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FIRE INVESTIGATION HANDBOOK

Francis L. Brannigan, Editor

University of Maryland Fire & Rescue Institute
Adjunct Staff
College Park, Maryland 20742

Richard G. Bright and Nora H. Jason, Editors

Center for Fire Research
National Engineering Laboratory
National Bureau of Standards
Washington, DC 20234

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Abstract

The Handbook is a reference tool designed to be used by the beginning or by the experienced fire investigator. How each person uses this book will depend upon a particular need and level of experience. The broad areas covered are: Fire Ground Procedures; Post-Fire Interviews; The Building and Its Makeup; Ignition Sources; the Chemistry and Physics of Fire and Sources of Information. The appendixes have sections on how to organize an arson task force; the expert witness; independent testing laboratories; and selective bibliography.

Key words: Accelerants; arson; building fires; electrical fires; explosions; fire investigators; hydrocarbons; photography

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Preface

The Fire Investigation Handbook is a tool to be used by the investigator with a lot of experience or the investigator who is new to the profession. How each investigator uses this Handbook will depend upon their individual needs and background.

There are several textbooks on fire investigation (see appendix D). This Handbook is not intended to replace these books. Nor is the Handbook a legal reference manual. The Handbook contains ready-reference information and highlights subjects essential to a comprehensive fire investigation.

As you, the reader and user, become more familiar with the Handbook, we would like to know what you think about the book. Are there any areas of interest that should be discussed more fully? Are there any areas that may be shortened? Are there any other areas that should be added? The editors are interested in incorporating the most important information in the Handbook. The use of the Handbook in the field will be a test of its contents and we look forward to receiving your comments. Please send them to:

Ms. Nora H. Jason
National Bureau of Standards
Bldg. 224, Room B250
Washington, D.C. 20234

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Introduction

In the Indian folk tale, the Blind Men and the Elephant, each man perceived the elephant differently. Fire investigation, also, is perceived differently by different investigators. To some, it is limited to determining whether a fire was criminally caused and, if so, apprehending and charging the perpetrator. Others broaden their interest somewhat to determining the specific cause of any fire.

The editors have taken an even broader view. Fire investigation should not be limited to solely determining the cause of the fire. The fire investigation should include the examination of all the circumstances of the growth and extension of the fire. In short, the cause of a fire is one matter; the cause of a conflagration can be quite another, and may be more important.

There is great difficulty in writing a handbook on fire investigation that takes this broader view on the existing state of the art; the entire field of fire technology could be discussed. Hard choices were made as to what was included and what was excluded.

There are many laws intended to protect the citizenry from the effects of fire. The enforcing of these laws is usually assigned to the "fire prevention" arm of the fire department. The word itself is misleading, because many of the laws assume that a fire will occur and they are designed to deal with the consequences of a fire. There can be no clear line of separation between "fire investigation" and "fire prevention". Much of what the investigator needs to know about the job is sometimes loosely called "fire prevention" or "fire science theory". There is no limit to what the fire investigator should know, but there are practical limits as to what one person can know. It is most important that the investigator understand the limits of his/her knowledge and the importance of getting expert advice when necessary.

Handbooks, including this one, present recommended procedures, laboratory data and test data. The observations and interpretative skills of the authors and editors also have been incorporated into the text. In turn, the text has been reviewed by a representative peer group. This technique has provided rich resource material from which

the editors and contributors could draw upon for this edition. No one procedure is offered as "the only way" or "the best way" of performing it.

The investigation of automobile fires does not involve the same type of information and techniques that one needs in investigating structural fires. The National Automobile Theft Bureau is maintained by over 400 insurance companies writing fire and theft insurance. It has a staff of specialists who can assist in automobile fire investigations, as well as work with law enforcement agencies. To assist the fire investigator, the Bureau published a "Manual for the Investigation of Automobile Fires". The Manual provides the fire investigator with a broad outline to be followed throughout the entire investigation. To avoid duplication of effort, this Handbook will not discuss automobile fires.

1. Fire Ground Procedures

1.1 DETERMINING THE ORIGIN AND CAUSE

1.1.1 Introduction

The fire has been extinguished and the call has gone out for the fire investigator. Pending the investigator's arrival, the fire scene perimeters should be determined and secured against unauthorized entry. Generally, a fire officer or police officer can control the scene until the investigator arrives and, based on recent court decisions, the control of the scene should be continuous from suppression through the investigation. The officer controlling the scene also should be aware of the specific laws in the jurisdiction with regard to the property owner and his/her access to the premises. In all cases, it may be necessary to post a guard at the scene with instructions to permit entrance only to persons with authorization.

When the investigator arrives, or perhaps even before, a decision should be made as to the safety of the structure remaining. Free-standing brick walls may have to be pulled down and holes in floors marked or barricaded. No changes in the structure should be made, however, other than those absolutely necessary for the safety of personnel until after the investigation has been completed.

In determining the origin and cause of fires, there is an important step which is sometimes overlooked and that is the gathering and utilization of all of the information about the fire that is already known and available. This includes information given by the person or persons reporting the fire, information received by the alarm dispatcher, information from the fire department personnel responding to the fire (particularly the "first-in" company), and information from any eyewitnesses. The type of information which may be obtained from firefighters is described in chapter 1.7. One method of developing information from eyewitnesses is covered in chapter 2.1 and possible legal problems are covered in chapter 2.2. The gathering of this available information may be done before the fire scene is examined, after the fire scene is examined, or some combination of these sequences. The circumstances of each fire will dictate which sequence should be used. But the point is that this information should be gathered if the investigation is to be a complete one. All of this information will need to be verified with what is observed at the fire scene, particularly if some of the information received is contradictory.

The primary purpose of a fire investigation is to determine what caused the fire, and whether it was accidental or incendiary. In most fires, the first step is to determine where the fire originated. Determining the origin narrows the search for and frequently pinpoints what caused the fire. The first part of this chapter will examine the process of determining the point of origin of the fire. The second part will examine the process of determining what caused the fire.

It is often necessary to develop detailed information on the various factors which led to, or caused, the fire. This information may include the source of the heat of ignition, that is, the specific equipment that provided the heat which started the fire, and the form of that heat (for example, flame, spark, hot surface). It also may be important to determine what was first ignited; both the type or composition of the material (for example, fabric, flammable liquid, plywood) and its form or use (for example, bedding, fuel, interior finish). The reason why the heat and the material combined to start the fire, that is, the ignition factor (for example, mechanical failure, children playing, incendiary/suspicious) also is an important item of information.

When combined, this information provides a detailed description of what caused the fire. An example of an investigation done to this level of detail is presented in chapter 4.5. It is, however, not always possible or necessary to go to this level of detail, particularly in the initial stages of an investigation. It is, therefore, useful to group the detailed information into a small number of general categories which still provide considerable information on what caused the fire. These categories are called the fire causes. They enable the investigator to eliminate possible reasons that a fire started, or to determine the probable reason, without developing all the detailed information on the sequence of events which led to ignition.

In some cases, determination of the cause may be sufficient. In others, the investigator may quickly determine the cause and then develop more detailed information on that cause. A list of fire causes, and their overall national frequency in residential fires for January-December 1978, is given in table 1.1.1-1. Similar fire causes and frequencies are not available for commercial/industrial properties at this time.

Table 1.1.1-1 Causes of United States Residential Fires - In Percent - 1978

Fire Causes	Fires	Deaths	Injuries	Dollar Loss
Heating	19	13	13	18
Cooking	16	6	15	6
Incendiary/Suspicious	11	7	8	15
Smoking	10	22	18	8
Electrical Distribution	8	5	6	10
Appliances and Tools	7	3	4	5
Children Playing	6	6	8	5
Other Equipment	4	2	5	4
Exposure	3	1.1	1.1	4
Natural	1.1	0	0.5	1.2
Open Flame, Heat	4	3	5	4
Other Heat	2	0.8	2	1.6
Unknown	10	31	15	19

Source: Highlights of Fire in the United States, 2nd edition, National Fire Data Center, U.S. Fire Administration, Washington, DC 20472, undated.

1.1.2 Determining the Point of Origin

Determining the point of origin of a fire can range from being readily obvious to almost impossible. An example of the former would be a sofa fire in a dwelling where the fire department was on the scene quick enough to confine the fire to the sofa. An example of the latter would be an early-morning-hour fire in a large furniture warehouse which was totally destroyed upon arrival of the "first-in" fire company. Most fires the investigator will encounter will be somewhere in between these two extremes. Even in those cases bordering on the impossible, it may be possible to determine the origin of the fire from eyewitness accounts.

1.1.2.1 Exterior of the Structure

Examine the exterior of the structure - note fire damaged areas, such as:

1) Charring and/or smoke deposits over doorways and windows;

2) charring and/or smoke deposits around attic vents and eaves or soffits.

Determine, if possible, whether doors and windows were open or closed at the time of the fire. Doors resist fire effects longer than windows. If there are little or no fire effects over a doorway while an adjacent window shows fire effects, it is likely that the door was closed at the time of the fire. On the other hand, if the fire effects over the doors and windows are similar, it is likely that the door was open during the fire.

Look for evidence that the fire may have started on the outside of the structure (commonly trash and brush fires) and spread into the structure through openings such as windows, vents, and the like. Char patterns on the exterior of the structure leading up and through an opening are definite indications the fire started externally and spread into the structure.

If a large area is involved, such as a lumber yard or a row of buildings, viewing the scene from a higher elevation, such as from a nearby taller building, an aerial platform, or possibly a helicopter, can provide an overall view of the fire scene.

Wind may influence the spread and pattern of external fire damage. This should be taken into consideration when examining the exterior of the structure.

1.1.2.2 Interior of the Structure

As a general rule, one should begin the interior examination by beginning with the areas and rooms with little or no damage and working towards the areas or rooms with the most damage.

1) Start with the lightly smoke-stained areas moving towards the heavily smoke-stained areas.

2) Proceed from areas of light heat damage towards areas of heavy heat damage. As a clue to the buildup of heat look for sagging paint (oil-based paints, primarily) and blistered paint.

3) Move into the most severely burned area or areas.

At this point, the investigator should be in the room or area where the fire originated.

1) Try to establish the lowest point of burning in the room. Look for definite patterns of fire travel upwards and outwards from this lowest point in the shape of a "V" on nearby or adjacent walls. If the fire began in the center of the room or area, there may be no "V" patterns. It will be helpful to look under furnishings, shelving, and window sills for evidence of fire damage as an indicator of low points of burning.

2) Check ceilings over the apparent fire origin for signs of more extensive damage than adjacent areas. If the ceiling over the apparent origin appears relatively undamaged but is lighter in color than adjacent ceiling areas, chances are this lighter area has been subjected to higher heat and/or direct flame impingement which has burned away the smoke deposits. If such a condition is found, this usually indicates that a hot fire occurred directly below and may be an indicator of the point of origin.

3) Look for direction of heat flow as confirmation or indication of the fire origin. As the heat flow will be primarily along the ceiling, examine light fixtures, light bulbs, and other materials at the ceiling level. Light bulbs begin to swell and distort around 900° to 1,000°F (482° to 538°C) when exposed to heat. If the heat continues to rise, the bulb may blow out in the direction of the heat source leaving a point. If the heat continues to rise, however, the glass may soften and begin to flow and this heat flow indicator will be destroyed. Plastics at the ceiling level will soften and melt at temperatures much below those of light bulbs. Temperatures of 200° to 400°F (93° to 204°C) will cause these changes in plastics.

4) Glass objects, including window glass, often will give clues as to a fire's location, as well as its intensity and rate of buildup. Glass further from the fire will have heavier soot and smoke deposits than glass which is closer. Window glass will expand under fire exposure and due to the confinement within the window frame, will break. Part of the glass usually falls out of the frame and part remains within the frame. Window glass fragments in large pieces with heavy smoke deposits usually indicates slowly developing fires. Crazed or irregular pieces with light smoke deposits indicate a rapid buildup of heat. Pieces of glass found with rounded edges indicate exposure to temperatures in excess of 1,400° to 1,600°F (760° to 871°C), the softening point of glass. Glass does not have a well defined melting point, melting anywhere between 2,000° and 2,600°F (1,093° to 1,427°C). While this is so, the presence of melted glass does indicate a hot, intense fire. However, it should be noted that thin glass requires much less time at high temperatures before melting than does thick glass. Thus, melted light bulbs may indicate nothing more than a short burst of high heat.

5) Floors seldom receive damage similar to that of ceilings, even in the case of total burnout, as the heat of the fire will be concentrated at the ceiling. In addition, as ceiling materials are damaged and fall, these materials protect the floor below. If, on the other hand, a large area of the floor is extensively damaged, the use of accelerants may be indicated. Keep in mind, however, that plastics used in furniture, mattresses, drapes, and other interior decorations, can give the appearance of a flammable liquid burn and must be considered to avoid improper conclusions.

6) Look for evidence of multiple fire origins. If the fires appear to be unrelated or discontinuous, the fires may have been deliberately set. However, multiple fires in a room, all originating from one fire are not uncommon. High-heat-producing fuels, such as plastics and interior finishes, can cause a degree of fire damage sufficient to mislead the investigator. Also, when ceiling temperatures reach 932° to 1112°F (500° to 600°C), flashover may occur when literally the entire contents of the room burst into flames simultaneously. The results of flashover which may cause the investigator to conclude there were multiple fires when such was not the case. The questions to be answered on apparent multiple fires are: Were these fires the result of normal fire spread from fuel load to fuel load, either by flashover, burning materials being carried around the room by the effects of the fire, or other mechanisms? Or were the fires independent of each other and, therefore, of suspicious origin?

7) Sometimes it is important for fire investigation purposes to know whether doors were open, partly open, or closed during the fire. Here are some of the things to look for in answering this question:

a) Closed doors - damage on only one side of the door. Hinges and the inside faces of the door frame may be free of smoke and heat effects, but not always;

b) open doors - damage on both sides of the door. Hinges and inside faces of door frames will be heat and smoke stained;

c) partially-open doors - same comments as b). However, there may be relatively undamaged portions of the floor in the doorway opening directly below where the door was positioned. Check for this.

If the positions of the doors were changed during the firefighting operations, observations a-c may not be valid.

8) In determining whether the fire was a slowly developing one or a rapidly developing one, the following indicators may be used:

a) Alligatoring of wood - slow fires produce relatively flat alligatoring. Fast fires produce hump-backed, shiny alligatoring. These observations apply, however, to unfinished lumber. Wood which has been painted or finished exhibits different characteristics depending upon the type of finish and thickness of the finish. Sometimes, taking a cross section of the wood exposed to a fire gives a clue as to the type of fire. A distinct line between the charred and uncharred portions indicates a rapidly developing fire. Lack of a distinct line usually indicates a slow, cooking process, thus, a slowly developing fire.

b) Spalling of concrete - indicates an intense, high heat fire. The spalling is caused by rapid boiling of the moisture trapped in the concrete.

c) Fire patterns - a wide angle or diffuse "V" pattern generally indicates a slowly-developing fire. A narrow sharply defined "V" pattern generally indicates a fast-developing, hot fire.

d) Ceiling damage - if the ceiling exhibits uniform damage, a slowly-developing fire is indicated. Extensive ceiling damage in one place indicates a rapidly-developing fire directly below the damaged location.

1.1.2.3 Summary

A systematic study of the fire scene is usually necessary to determine the origin of the fire, the first step in establishing the cause.

The physical evidence developed during the investigation should be checked against the statements of witnesses. The two may reinforce one another, or the two may conflict. It is important that the investigator try to resolve any conflicts. While it is important that the investigator keep an open mind, do not forget that witnesses' accounts may be less than reliable, particularly if they have had little experience with actual fires.

The quicker the fire department can extinguish the fire, the easier it will be for the investigator to determine the point of origin and establish the cause. On the other hand, if the fire department is relatively unsuccessful in preventing a total loss for one reason or another, finding the origin (and cause) will be extremely difficult. However, even in the extremely difficult situations, intelligent use of all of the available information, including that from witnesses, may permit the investigator to assign a "most probable cause" with reasonable accuracy.

1.1.3 Determining the Cause

1.1.3.1 Introduction

Once the point of origin has been determined, the cause of the fire is next. Causes of fires can be categorized as accidental or incendiary. Accidental causes include heating, cooking, smoking and similar causes. The word "incendiarism" will be used in its broadest sense, that is, the intentional burning of property. Arson, which is a felony or crime, is the deliberate setting of a fire for illegal gain or with malice.

1.1.3.2 General

There are two ways to approach fire cause determination. One is by a process of elimination, that is, by eliminating all known causes of fire until only one or two possible causes remain. For example, if there was no heating, cooking, or electricity present, then these causes are automatically eliminated from consideration. There is one caution with this approach. The investigator must be sure that none of these possible fire causes were present on a temporary basis. For instance, if the workmen on a construction site have been known to build small fires for heating foods for lunch or for warming themselves during cold weather, then cooking and heating cannot be eliminated from consideration even though the building's permanent utilities have not been completed.

The second approach to fire cause determination is the reverse of the above. In this approach, the investigator would ask: "What was present that could produce ignition? Was there heating equipment in the area of origin that could have produced a spark or been overheated? Was there a possibility of an electrical short circuit? Were smoking materials involved? Was there any sign of an explosion?"

Either approach will work and both have the effect of forcing the investigator to systematically consider all possibilities. Whether the investigator uses one or the other, or some combination of both, will depend on the investigator's inclination or the circumstances of the fire. However, if the fire appears to be incendiary and there is a suspicion of arson, then the elimination approach should be used. To establish the corpus delecti of arson requires that all possible accidental causes be eliminated or, if they cannot be eliminated, the determination as to why they did not or could not have caused the fire must be made.

As one closes in on the fire cause, photographs and sketches of the indicators and evidence as to the fire cause can be extremely helpful, particularly if the investigator feels that reference to the case may be necessary at some future time (as in civil or criminal litigation, for example). (It is assumed that the investigator has already sketched and photographed the buildings, its surroundings, and the area or room of origin.) Chapter 1.3.3 describes sketching of the fire scene and chapter 1.5 describes photography skills for fire investigators.

Tools and equipment a fire investigator may need are described in chapter 1.3. Chapter 1.6 presents information on the development and maintenance of records on fire investigations. How buildings are constructed and the materials they contain are covered in chapters 3.1 to 3.3. All fire investigators need some understanding of fire phenomena and this is covered in chapters 5.1 to 5.5. Ignition sources and processes, which are fundamental to determining fire causes, are described in chapters 4.1 to 4.6. In the next section fire causes, in general, will be discussed. Fire causes with the highest frequency will be presented first, following the order in table 1.1.1-1.

1.1.3.3 Fire Causes

It is well to remember that a fire needs both a heat source and a fuel supply as discussed in chapter 1.1.1. Heat sources can include sparks, embers, flames, arcs from a short circuit, heated surfaces, and smoking materials. These heat sources may be from normally operating equipment or from equipment which has malfunctioned. Fuel supplies may be combustible solid materials, or combustible or flammable liquids, or gases. As an example of the need for both a heat source and a fuel supply, water entering a metal junction box in a plastered ceiling can produce heat from the partial shorting of the wiring, but it will not ordinarily produce a fire. If, on the other hand, the metal junction box is attached to a wood member above the ceiling, then the heat produced by the water-induced shorting can result in ignition of the wood. A concealed fire could develop above the ceiling.

1) Heating equipment - includes central heating systems (gas, oil, coal, wood, or electric), fixed or portable local heating units, fireplaces and stoves, chimneys, and water heaters. Some of the things to look for are improper installations which may have produced overheating of nearby combustibles over a period of time, heating equipment driven hard during cold spells, or backfires.

2) Cooking equipment - includes stoves and ovens (either gas or electric), portable cooking or warming units (such as deep fat fryers, toasters, coffee makers, table ovens, and electric fry pans). Stove and oven fires are frequently from unattended cooking. Stove top fires can involve the wooden cabinets above the stove, often resulting in severe fires. Most portable cooking units are equipped with thermostatic controls to regulate the cooking temperature. In many of these units, failure of the thermostat, for one reason or another, results in the appliance remaining "ON". This can produce a runaway condition which results in a fire.

3) Incendiary/Suspicious - fires deliberately set or with suspicious circumstances. There will be occasions when all possible accidental fire causes have been reviewed and none fit the circumstances. The investigator has two options at this point: List the cause as unknown or list the cause as incendiary. Usually, to list a fire cause as incendiary requires some evidence or clues pointing in this direction. Some of the clues one should look for are:

a) Trailers (connections to or between fire sets);

b) candles used to ignite fire sets or trailers. (Candle wax rarely is consumed completely in the ensuing fire);

c) discarded matches in out-of-the-way places;

d) chemicals unusual for the occupancy;

e) rags, clothing, or curtains soaked in oils;

f) timing devices;

g) tampering with or other unusual arrangements of electrical equipment and appliances;

h) disturbed or broken gas piping, including gas burners in the "ON" position;

i) unexplained multiple fires;

j) rearrangement of the contents of a room or area in an unnatural way, conceivably to assist the fire;

k) accelerant containers or accelerant patterns or other evidence of flammable or combustible liquids. Look for unusual burn patterns such as heavy burning at the joints in wood flooring and tile flooring. Check for hydrocarbon accelerants using a detector (see chapter 1.2).

If any of these or other clues are found, the fire investigation shifts directions and a somewhat different procedure will be necessary. Chapter 1.4 describes evidence gathering and should be consulted. There are several good texts on arson investigation, some of which will be found in appendix D. These texts should be consulted if the fire appears to have an incendiary origin.

4) Smoking - includes cigarettes, cigars, and pipes as ignition sources. Smoking materials, and cigarettes in particular, produce smoldering combustion, which may lead to flaming combustion. This topic is covered in detail in chapter 4.2.

5) Electrical distribution - includes wiring, transformers, panelboards, power switching gear, generators, outlets, switches, and lighting fixtures. Chapters 4.4 and 4.5 cover electrical distribution systems as fire causes.

6) Appliances and tools - includes television sets (TVs), radio and hi-fi systems, dryers, washing machines, vacuum cleaners, separate motors, hand tools, electric blankets, and irons. Dryer fires usually originate from overheating of the clothes in the dryer, either due to failure of the controls or the likelihood of certain materials to ignite during the drying process (clothing items containing foam rubber, for example). Dryer fires are usually confined to the dryer unless the vent pipe passes close to or through combustible materials. Electric blankets have a history of causing fires, either due to failure of the blanket controls or to improper use, such as folding the blanket, tucking the blanket under the mattress, or covering the blanket with other bedding which traps the heat inside the electric blanket. Domestic irons normally operate safely as their temperature is limited by a

thermostatic control. Failure of the thermostat can allow the iron to overheat and, if placed on combustible materials, a fire can result. Even if the iron is set on its base, the soleplate, if aluminum, can melt and flow down, setting fire to the ironing board cover. See chapter 4.4 for additional information on electrical appliances and tools as fire causes.

7) Children playing - includes all fires caused by children playing with any materials. This category includes accidental fires only, and excludes deliberately set fires, which fall under incendiarism. Probably the most frequent fire cause involving children is playing with matches and lighters. Generally, the age group for this type of play activity is between three and seven years of age, though these are not hard and fast age limits. Some clues to this type of fire cause are unexplainable fires in closets, in bedrooms, under beds, in sheds, where one or more young children were present, and they were not under close supervision just before the fire was discovered. Turning on one or more burners of kitchen stoves is another play activity of young children that occasionally results in fires. If there is food on the stove, the food may overheat and ignite. Gas burners, if left on for a period of time, may ignite wooden cabinets above the stove if there are no pans on the "ON" burners. Newer stoves have controls which have been made difficult, but not impossible, for young children to reach. But there are many older stoves still in use which have the controls in front where children can reach them.

8) Unknown - includes fires for which the cause was undetermined or not reported. This category accounted for 10 percent of all fire causes, 31 percent of the fatalities, 15 percent of the injuries, and 19 percent of the loss in 1978 (see table 1.1.1-1).

The remaining cause categories from table 1.1.1-1 are: Other Equipment (4%); Exposure (3.3%); Natural (1.1%); Open, Flame, Heat (4%) and Other Heat (2%). These will not be described in detail, other than to state what is included in each as a way of alerting the investigator to other fire causes to be considered.

1) Other Equipment - includes fires in special equipment (X-ray, computers, vending machines, copy machines, pumps, printing presses), processing equipment (furnaces, kilns, other industrial machines), and service and maintenance equipment (incinerators, elevators).

2) Exposure - includes fires spreading into a structure from fires in trash, brush, grass, and other structures.

3) Natural - includes fires caused by the sun's heat, lightning, static discharge, spontaneous ignition, and chemicals.

4) Open Flame, Heat - includes fires from candles, torches, matches, lighters, and backfires from internal combustion engines.

5) Other Heat - includes all other fires caused by heat from fuel-powered objects and heat from hot objects not covered in the above categories.

Some tables that list fire causes will include gas and flammable or combustible liquids as cause categories. Gas and flammable/combustible liquids are fuel sources, however, not heat or ignition sources. While fuel identification is always important in fire investigations, to determine the cause, as defined here, the investigator must determine what was the heat or ignition source for the gas or liquid, not what was ignited. Note, however, that incendiary fires involving flammable liquid accelerants are covered under the incendiary/suspicious cause category.

The fire causes listed constitute about 99 percent of all fire causes. In many of the fires an investigator attends, the cause will be obvious, either because of eyewitness' accounts or because of indisputable evidence. In other fires, there may be no clear indication as to the fire cause. It is in situations such as these that the above list of fire causes will be the most helpful. Diligent use of the list by the fire investigator will ensure that all fire causes have been considered and, hopefully, the process will pinpoint the fire cause beyond a reasonable doubt.

It is possible to assign a cause of, say, "Electrical Distribution" to a fire and go no further than this, even though such a broad cause category tells little about the incident. However, most investigators will want to go beyond such a simplistic cause assignment. Chapter 4.5 gives an example of how an investigation can be taken to considerable length to establish the precise failure mechanism that caused the "Electrical Distribution" fire. Probably, most fire investigations will be between these two extremes. The workload of the investigator, the resources available, and the nature of the incident undoubtedly will be the primary factors determining how thoroughly the fire is investigated. However, the more thorough the fire investigation, the more accurate will be the fire cause determination and the more detailed the information developed for subsequent reporting. This, in turn, may well lead to pinpointing deficiencies in codes and in appliances and equipment which could lead, ultimately, to improvements.

1.2 DETECTION OF HYDROCARBON ACCELERANTS

1.2.1 Introduction

The use of an accelerant, usually a petroleum distillate (hydrocarbon) such as gasoline, kerosene, or diesel oil, is common in incendiary fires. It is necessary that the accelerant be identified. Equipment and techniques are available to do this.

1.2.2 Detection of Accelerants Using Combustible Gas Detectors

Accelerants, such as petroleum distillates, are readily absorbed into many building and furnishing materials, such as upholstery, bedding, carpets and other porous substances. After extinguishment, accelerants often remain in the partially burned material. Thus, vapors can be detected for an extended period of time.

The detection of accelerants at an incendiary fire scene includes the use of portable (hand-held) combustible gas detectors capable of indicating trace amounts of flammable vapors. These instruments include those with manual or motor-driven pumps for sampling (sniffing) the atmosphere at the fire scene. Generally, the instruments employ a detector (sensing device) which produces a signal, indicated by a meter reading, as a result of heat generated from catalytic combustion of hydrocarbon vapors sampled from the atmosphere.

The typical combustible gas indicators used for the detection of hazardous gas/air mixtures may not be sensitive enough to detect trace quantities of accelerants. If any quantities of accelerant are detected, samples should be sent to the testing laboratory where a gas chromatograph can be used to identify the specific material involved.

The detector's signal strength is determined primarily by the amount of fuel vapor in the air and to a lesser extent by the type of fuel present. The composition of an accelerant after the fire is determined by the length of time the accelerant is exposed to heat and other atmospheric conditions. It is, therefore, useful to know the response of a given detector to various accelerants under simulated fire scene conditions, as well as substances which may produce false readings.

It is recommended that the directions of the detector manufacturer be followed for proper use. However, there are substances, such as airborne soot particles and some types of small dust particles, which may produce false readings of combustible vapors. On the other hand, heavy metal compounds (for example, lead in leaded gasoline) may cause a decrease in sensitivity because of the deposition of metal on the catalyst (usually platinum) of the detector. The use of a filter in the probe of the detector can reduce the effects of particulates and lead. The use of reference accelerants can readily indicate any significant change in the sensitivity of the detector.

1.2.3 Investigating the Fire Scene for Accelerants with Combustible Gas Detectors

This phase of the investigation normally takes place after the fire scene has sufficiently cooled and the origin of the fire located (see chapter 1.1). The purpose now is to locate building and furnishing materials or other articles which may contain residual accelerants.

The detectors may be used to locate specific items from which vapors are evolving, including those which are odorless. There are special detectors which can accurately detect even trace quantities of accelerant. Therefore, the suspected area of origin should be tested (sniffed) with the probe of the detector for the specific location(s) of residual accelerants. These areas include the following:

1) The underside and inside of furnishings, for example, floor coverings, furniture, cushions, and mattresses;

2) crevices and cracks in floors, behind baseboards, in joints between the treads and risers on stairs;

3) the surface of any standing water used in extinguishing the fire.

1.2.4 Specimen Collection for Identification of Accelerants

The objective is to collect specimens with evidence of combustible vapors. Collecting these specimens may require removing portions of building materials and furnishings, as well as collecting samples from pools of water. In the case of masonry materials, such as concrete, accelerants may be collected from them by using absorbent powders such as talcum or powdered chalk (calcium carbonate). Removing concrete chips from the fire scene may achieve the same purpose.

The collected samples should be placed in vapor-tight containers for submission to a laboratory for identification of the specific accelerant. It is also important to take comparable specimens from areas not involved in the origin of the fire as reference samples and submit them to the laboratory with the specimens which indicate the presence of accelerants. For additional information, see chapters 1.3, 1.4 and 1.6.

1.3 TOOLS AND EQUIPMENT

1.3.1 Introduction

The on-site investigation of a fire is most important. It can be time consuming and arduous. The proper tools make the task easier and more successful.

1.3.2 Basic List

Certain basic equipment is necessary. The inventory may vary depending upon the investigator's experience and preference, as well as available funds. Where there are several investigators, expensive sophisticated equipment may be shared. Some agencies have developed response vans which contain elaborate equipment.

The investigator's vehicle should have a 2-way radio on both fire and police frequencies and a portable radio (walkie-talkie) and should be equipped for emergency response. Unmarked vehicles are probably more suitable as marked vehicles may be a deterrent to potential witnesses.

Experience and common sense will dictate the manner in which the following tools and equipment are useful. The list is intended as a general checklist, not a specific guide.

1) Ax - fire department pick head type;

2) broom (or small brush, "foxtail", or both);

3) photography equipment - for fire ground use in taking photographs to reconstruct the fire scene (see chapter 1.5);

4) cardboard boxes;

5) claw hammer;

6) combustible gas indicator or hydrocarbon detector - for use in determining presence of an accelerant during fire scene examination (see chapter 1.2);

7) hacksaw;

8) knife;

9) handsaw;

10) flashlight and hand lantern;

11) magnifying glass - valuable for examining details;

12) marking pencil - waterproof felt pen or crayon-type pencil for use in marking evidence and locations for search;

13) containers with lids - for use in transporting small items for examination, especially those suspected of containing flammable liquids (new paint cans);

14) notebooks and pencils - for recording of observations and statements;

15) pliers;

16) pry bar;

17) rake - for sifting through debris;

18) sand screen - for use in sifting for minute evidence in debris;

19) screw drivers - several sizes, both straight blade and phillips;

20) shovel - for debris removal;

21) sponges - for removal of suspect debris of liquid nature;

22) clip board with paper - for drawing sketches and diagrams of fire scene;

23) pipe wrench;

24) tape recorder - a valuable aid for taking statements and recording observations;

25) tape measure - for measuring fire scene and other areas for sketches;

26) towels and rags - for use in a variety of ways during the fire scene examination;

27) bags, different sizes, both paper and plastic - for use in transporting dry evidence which does not contain a flammable liquid;

28) string or rope - for marking areas off-limits or work areas;

29) a large pail or garden sprinkling can - for water to be gently applied to the point of origin of the fire to make the area clean and to examine char patterns to determine the direction of flow of any flammable liquid used.

The list is intended as a general check list, not a specific guide. Some investigative agencies are purchasing portable gas chromatographs for detection and identification of accelerants. The devices can be of great value and may be assigned on a regional basis rather than to an individual investigator.

1.3.3 Sketching

The investigator will find it useful to make a sketch or diagram of the fire scene, as well as sketches of neighboring buildings and streets. Sketches supplement but do not replace photographs.

The equipment needed are soft pencils, eraser, a short (6 to 25 ft) measuring tape, a 50-100 ft steel tape, a clip board and 8-1/2" x 11" graph paper with square grids. (This paper is often referred to as 6 by 6 or 12 by 12, as it has 6 or 12 lines to the inch.)

Carefully measure the room or area being sketched and double check the measurements before leaving the fire scene. (Relate the photographs to the sketches as they are being made.) If the room or area is sketched as near to scale as possible, it will be easier to make the final copy. Note the placement of windows and doors; record their position of being "closed" or "open". Also record the chimney, electrical outlets and any other permanent features of the room or area. (If the gutted area is in an apartment building or a townhouse, it may be possible to obtain this information from a duplicate model.) If possible, placement of furniture and appliances at the time of the fire should be noted. An example of a sketch is shown in figure 1.3.3-1.

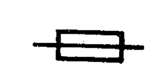
The following symbols are suggested for sketches. They are presented in six categories: Fire; Building Components; Utilities; Fire Protection Devices and Equipment; Furniture; People. In fact, the investigator may wish to develop a unique symbol system. Each sketch should include North, a scale to assist the viewer in developing a good idea of the size of the room, building, or outside area, the name of the person and date of sketch preparation, and a complete list of symbols used. The symbols listed below were selected from the NFPA Inspection Manual, 3rd edition, discussions with several fire investigators, and review of Fire Journal articles. The list is not exhaustive; it is included to illustrate the wide range of available symbols.

Fire:

★ - Point of Fire Origin

Building Components:

——— - Wall (may be labeled if the detail important, for example, wood)

 - Window

 - Door, open

 - Door, closed

- Door, sliding, open, showing direction
- Door, sliding, closed, showing direction
- Partition, subdividing, full height
- Partition, subdividing, partial height (for example, a room divider)

1 HR - Partition, fire rated or fire wall

E E - Elevators

SHAFT - Shaft

- Stairs, inside, enclosed, with return
- Stairs, inside, open, no return
- Fire escape, access from window

Utilities:

S - Electrical switch

- Electrical outlet, double receptacle

L - Light fixture, rectangular

L - Light fixture, circular

- Duct, horizontal

DUCT - Duct, vertical

Fire Protection Devices and Equipment:

AS - Automatic sprinkler head

H - Heat detector

SD - Smoke detector

FAB - Fire alarm box

FAB - Fire alarm box with bell above

FB - Fire bell

F F - Fire horn

FE - Fire extinguisher

FH - Fire hose

H&SD - Heat & smoke detector combined

Furniture:

COUCH - Couch

CH - Chair

BED - Bed

People:

- Location of victim
- Point of access or egress

The investigator should keep all rough drafts of the sketches. The final sketch may be "polished" and included as part of the permanent record.

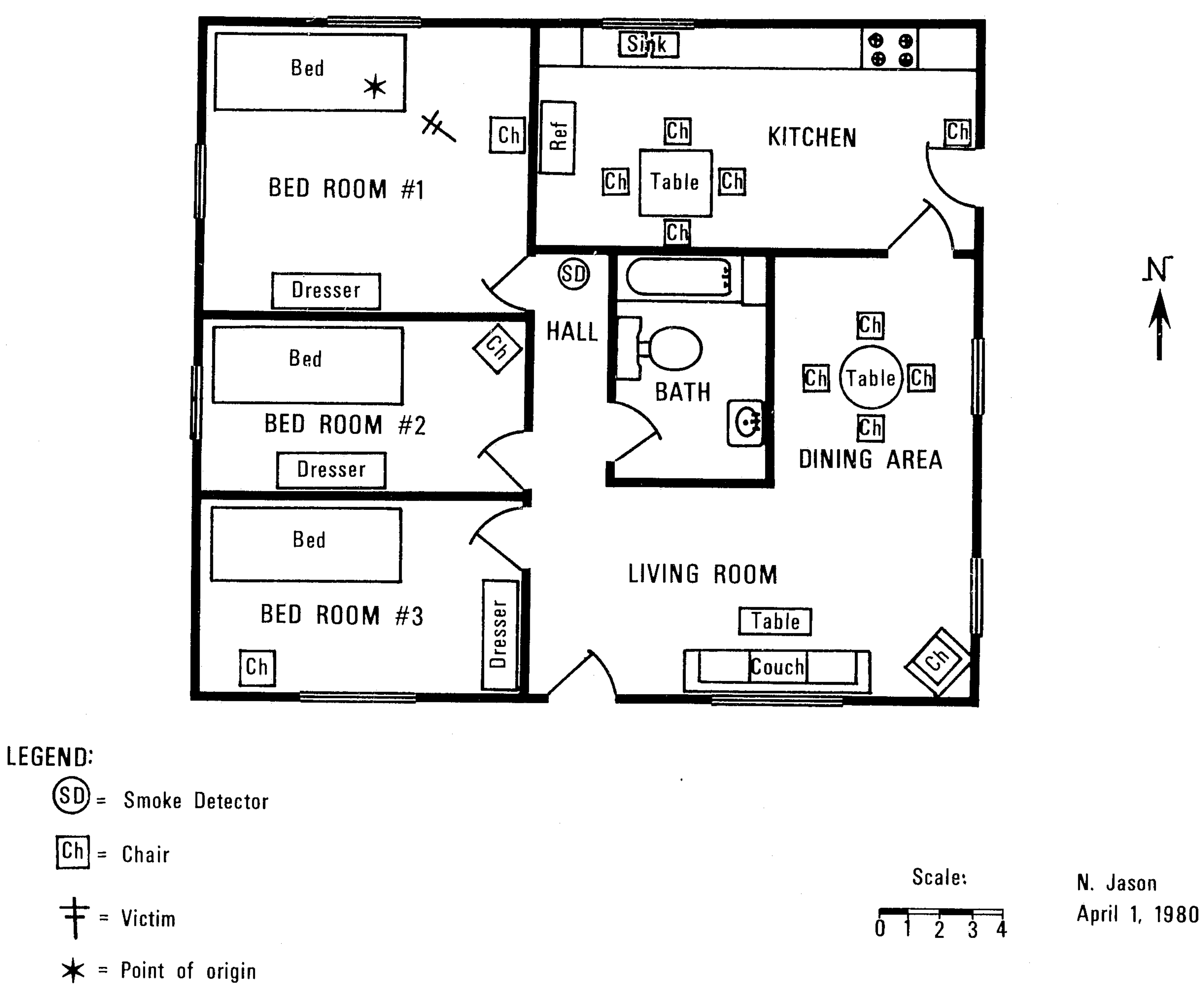


Figure 1.3.3-1

Investigators also may find it useful to photocopy the basic sketch and to use overlays for clarity or particular emphasis. For example, one overlay may have all electrical items noted, another will indicate furniture. For additional discussions of using sketches as evidence in court, refer to Harvey M. French's "Sketching Fire Scenes", chapter 21, in The Anatomy of Arson.

Another technique that may be useful for courtroom presentation is to prepare a diorama, a three-dimensional model of the fire scene. A large piece of poster paper, for example, may be used to "build" a room with walls and floor. The fire growth pattern can be drawn into the room, with as much furniture as can be identified, and a more vivid picture of the event can be presented. An example is shown in figure 1.3.3-2.

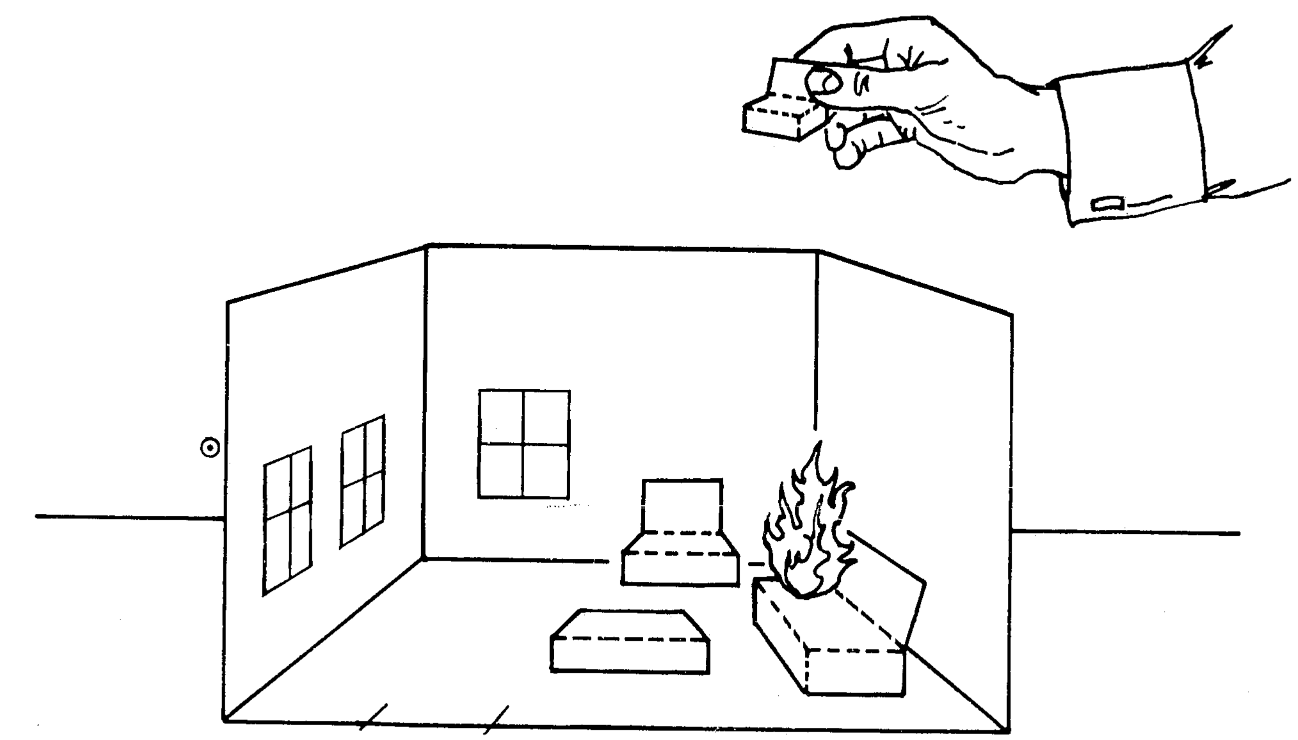


Figure 1.3.3-2

1.3.4 Summary

The investigator must be provided with the proper tools and equipment to get the job done. The investigator must also have on proper protective equipment. Fire investigation, including the determination of point of origin and cause is difficult at best and success only can be achieved if the investigator is equipped with the proper tools, photographic equipment, and sketching materials. It is with this combination that a comprehensive "picture" and detailed information can be obtained and recorded.

1.4 EVIDENCE - GATHERING, MARKING AND SAFEGUARDING

1.4.1 Introduction

Evidence, as used here, is any object which may be used to prove allegations in a civil or criminal trial. Evidence may take many forms. For example, a section of a jimmied door may be removed and qualified laboratory personnel can prove that the jimmie marks were made by a certain tool. Portions of paneling, ceiling tile, floor covering, and wallboard may be removed from the fire scene in order to show that the materials did not meet code requirements of the jurisdiction. If evidence is of the type that might link a particular person with a crime, care should be taken to avoid destruction of latent fingerprints. A common form of evidence in arson cases are samples of the structure or the contents which show traces of flammable liquids, foreign to the samples, which may have been used as accelerants.

The rules for handling evidence, and laboratory procedures vary from jurisdiction to jurisdiction. The investigator must be thoroughly familiar with local procedures, both court and laboratory procedures. "Contaminated evidence" may be ruled inadmissible by the court, and an otherwise well-prepared case may fail. Carelessness in handling evidence also should be avoided as this may be interpreted as willful destruction of evidence favorable to the defense.

The chain of custody of evidence must be maintained. It must be unbroken as it must show that the evidence offered in court is the same as that obtained by the investigator. Accurate documentation also is important because there may be a substantial time lapse between the time the evidence is obtained and a subsequent trial. It also is important that good notes are made as the investigator can use them to recall specific information. Incomplete records may cause the investigator to hesitate on the witness stand and the evidence to be inadmissible or, at the least, it may raise doubts in the minds of the jury.

1.4.2 Collection of Samples

If an accelerant was used, it may be very important to prove that the accelerant was foreign to the area in which it was found, and that laboratory findings were not due to some material legitimately in the area.

Before samples are taken, the area should be photographed. A sketch can be made on gridded paper (refer to chapter 1.3.3). Samples should be taken systematically and identified positively as to location within the fire area. Here the gridded sketch will be useful. Photographs also can be related to the grid.

If possible, samples should be taken from an unburned area, as well as the burned area. If this is not possible, they should be taken from the area where the accelerant was used, and other burned areas (to provide an uncontaminated sample). They should include, as far as possible, the same material, such as carpeting. Samples also should be taken in the area of origin from behind baseboards, from cracks in floors, at the joint of treads and risers in stairways and other locations where accelerant residues might survive the fire. If an accelerant was used on an upholstered chair or sofa, traces of the accelerant may be found behind the charred areas. (Charred areas tend to protect the accelerant from the effects of the fire.)

All samples should be properly packaged for storage and transportation. Samples of carpeting, wallboard, ceiling tile and other building components should be wrapped in plastic and sealed. Samples of flammable liquids are best packed in unused paint cans with tight-fitting lids. (Beware of internally-coated cans! The coating may react with the sample which will contaminate the sample.) It is good practice to check the can with a combustible gas detector before placing the sample in the can; in court the investigator can then testify that the can was not contaminated. If a sample for a gas chromatograph is gathered in a plastic bag, the bag must be removed before it is transferred to the can. In the laboratory the sample is heated and a gas sample is drawn off through a hole. The decomposition of the plastic would contaminate the sample; therefore, the bag must be removed. Glass containers may be used as a substitute for metal containers. Canning (mason) jars are recommended.

The above is for "headspace" sampling. Check with the laboratory that will handle the sample for any specific handling instructions and packaging procedures.

If large quantities of liquids are found, samples should be taken from each container to determine if they are flammable liquids. A sample from each container should be taken outside and field tested; poured on the ground and ignited. Again all steps should be meticulously noted and photographed.

Explosive or suspected explosive devices must be handled by qualified personnel with adequate equipment.

1.4.3 Tagging of Evidence

The following information should be collected and included on each tag:

1) Incident number;

2) incident date;

3) date and time evidence was collected;

4) identity of person who found the evidence;

5) identity of witnesses present;

6) location where evidence was found;

7) description of evidence;

8) identity of investigator;

9) file or storage number;

10) identity of individual receiving evidence (signature and date).

1.4.4 Maintaining the Chain of Evidence

The chain of evidence must be maintained from the time the evidence is obtained until it is presented in court. Evidence should be transported promptly to an evidence locker or room accessible only to designated personnel. All material should be logged in and out by procedures established in each jurisdiction. An example of a tag on "peel-and-stick" paper is shown in figure 1.4.4-1. A secure magazine, located in a safe area, should be provided for the storage of any type of explosive device. If evidence is sent to a laboratory, a letter of transmittal should accompany it (see figure 1.4.4-2). If evidence is transported by hand, receipts should be given and taken at each step. If evidence is sent by common carrier, local guidance should be obtained on receipt requirements.

CRIME SCENE SEARCH EVIDENCE REPORT

Name of Subject..........
Offense..........
Date of Incident..........Time..........AM-PM
Search Officer..........
Evidence Description..........
....
Location..........
....

CHAIN OF POSSESSION

Received From..........
By..........
Date..........Time..........AM-PM

Received From..........
By..........
Date..........Time..........AM-PM

Received From..........
By..........
Date..........Time..........AM-PM

Received From..........
By..........
Date..........Time..........AM-PM

Received From..........
By..........
Date..........Time..........AM-PM

Received From..........
By..........
Date..........Time..........AM-PM

Received From..........
By..........
Date..........Time..........AM-PM

Figure 1.4.4-1

DEPARTMENTAL LETTERHEAD

Date

Dr. Jane Doe
Chief, Forensic Staff
Number Street
Your City, Your State Zip Code

Dear Dr. Doe:

The enclosed samples taken from

Case Information:

a. Our Fire and Rescue Services, Incident #

b. Date of Incident,

c. Time of Incident,

d. Exhibits secured by

Exhibit Information:

Please test these samples to determine what is present in the sample.

Sincerely,

Signature block

Figure 1.4.4-2

Even if it does not appear initially that there will be a criminal prosecution, proper procedures should be followed for all material removed from the fire scene. The materials may become evidence at a later date and this possibility requires strict adherence to the chain of evidence procedures.

1.4.5 Summary

The obtaining, tagging, custody, and presentation of physical evidence is governed by strict rules. Failure to follow the rules precisely may cause months of hard work to be lost. To avoid this possibility, each jurisdiction should establish a reputation for "going by the book"; this should keep an inadvertent error from occurring.

1.5 FIRE INVESTIGATION PHOTOGRAPHY

1.5.1 Introduction

Photography is a useful tool for the investigator to document visual observations, emphasize fire development characteristics, and authenticate physical evidence found at the fire scene. The fundamental concepts of fire investigation photography, with emphasis placed upon a set of systematic guidelines for use by the "non-expert" photographer, are discussed. The objective is to produce useful and legally acceptable photographs for fire investigation reports and courtroom presentations as a fair and accurate representation of what the investigator saw at the scene.

1.5.2 Equipment

Fire investigators are not usually required to qualify as expert photographers, yet they must be able to understand and utilize their equipment for maximum benefit (1)[1]. With these guidelines in mind, the following recommended items could be included as the minimum equipment for fire photography to be carried by investigators.

1.5.2.1 Cameras

The most versatile cameras available to fire investigators are the 35 mm cameras, either the simple, one lens rangefinder type or the more sophisticated single lens reflex (SLR) type which can be used with a variety of lenses. With the introduction of electronically-operated shutter systems, the automatic 35 mm camera has become the recommended camera for fire investigation photography (2). Competitive pricing has placed the cost of many acceptable units around $100.00. Most automatic 35 mm cameras have compatible electronic flash units available. These are recommended for best results and maximum versatility. Figure 1.5.2.1-1 illustrates a typical 35 mm automatic camera and its nomenclature.

[1]Figures in parentheses refer to references at the end of the chapter.

DESCRIPTION

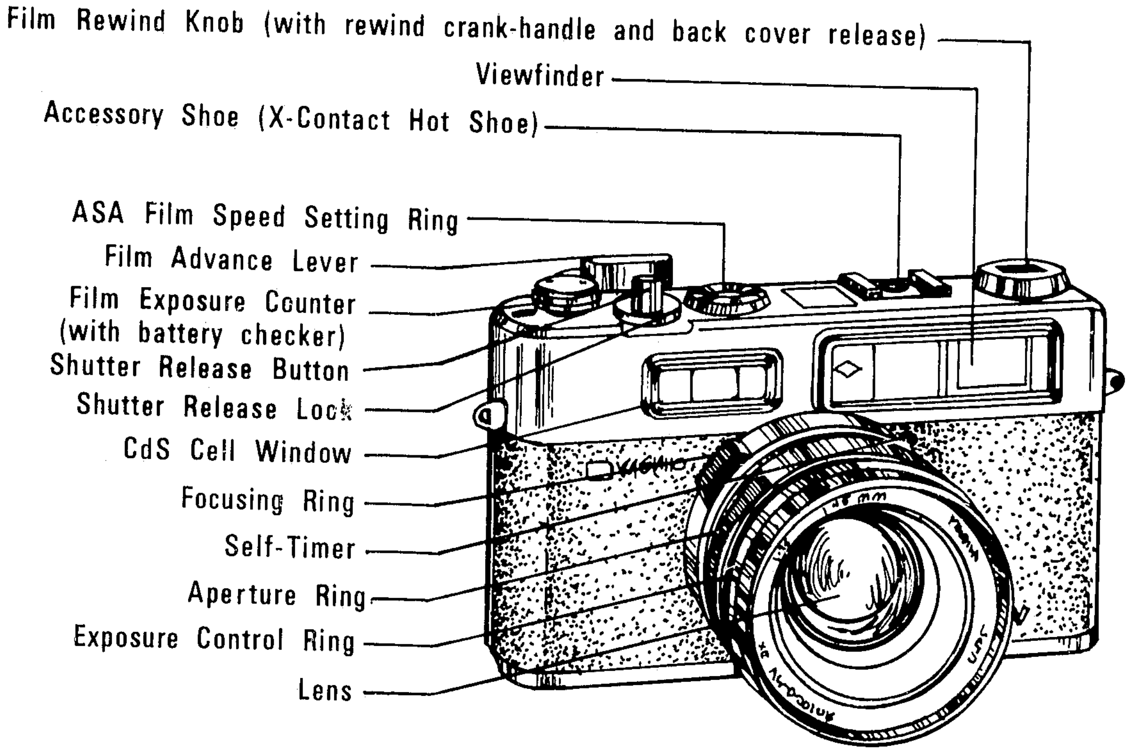


Figure 1.5.2.1-1

1.5.2.2 Films

Color slide (positive) film is easy to handle, mail, and view. If prints are needed, acceptable ones can be made from slides. Color print (negative) film is costlier on a per photograph basis. Black and white pictures, while the least expensive, are not as satisfactory in recording fire scene details (2).

Investigators often select slides for printing to include in reports or use in courtroom presentations. Printed photographs from slides do not reveal any noticeable degradation in color or clarity. Table 1.5.2.2-1 summa.'zes the presently available 35 mm negative films, as well as slide positive films. Films with higher ASA ratings require less available light. Some film, such as Ektachrome 400 slide film, can be shot at higher than normal ASA ratings (800) and when developed accordingly give acceptable slides.

Before and after exposure, films should be protected from moisture and excessive heat. Loaded cameras and spare film should not be left in glove compartments or trunks of vehicles (1). Film purchased in quantity should be stored at 55°F (13°C) or lower, such as in a refrigerator.

Table 1.5.2.2-1 Summary of Daylight Color Films for Fire Investigation Photography

Type	Manufacturer	ASA Rating
Negative (color print) film	Fuji - Fujicolor	100
	Fujicolor	400
	Kodak - Kodacolor	100
	Kodacolor 400	400
Positive (color slide) film	AGFA - Agfachrome	64
	Agfachrome	100
	Fuji - Fujichrome	100
	Kodak - Kodachrome	25
	Kodachrome	64
	Ektachrome	64
	Ektachrome	200*
	Ektachrome	400*

*Can be "pushed" to at least double the ASA number.

1.5.2.3 Accessories

Many lens and filter attachments are available for cameras; however, for the sake of simplicity, non-expert photographers are advised to limit their use. The lens provided with the camera can be used very effectively. The use of filters and interchangeable lens may disqualify photographs or slides in courtroom presentations when the investigator cannot adequately explain their uses, advantages, deficiencies, or effects. However, a skylight filter over the face of the lens can protect the lens from water and fire debris.

One recommended accessory for photographing fire scenes is a sturdy tripod. Under low light conditions, long exposures are necessary. A tripod will hold the camera steady while these long exposures are taken. Also, panoramic scenes from which mosaics can be prepared are more easily recorded using a tripod with a swiveling head. Figure 1.5.3.3-9 is an example of what the investigator can do with this equipment.

1.5.3 Photographic Technique

The proper use of an automatic camera, combined with a careful preplanning of investigation activities, is the best technique for non-experts. Several simple principles and concepts must be observed and understood by the fire investigator.

It is possible here to provide only a brief discussion of the basics of photography. If at all possible, the investigator should take a basic photography course and should attend any available seminar in fire or crime scene photography. In addition, the investigator should shoot several rolls of film under various conditions for practice before photographing actual fire investigations. The circumstances of each practice shot should be noted, and those which turn out poorly should be discussed with a competent photographer. The ability to hold the camera absolutely still for the instant the shutter is open comes only with practice.

1.5.3.1 Depth-of-Field

The term depth-of-field describes the furthest and closest ranges that a camera will photograph clearly at a given aperture setting (3). While an automatic camera selects the aperture according to the available light conditions automatically, a manual camera does not. Hence, the investigator must understand depth-of-field principles if he is to take clear photographs. Figure 1.5.3.1-1 illustrates an example where an aperture of f/16 will produce a depth-of-field ranging from 4.5 ft (1.4 m) to 10 ft (3.8 m) when the camera is focused at 6 ft (2 m) from the lens.

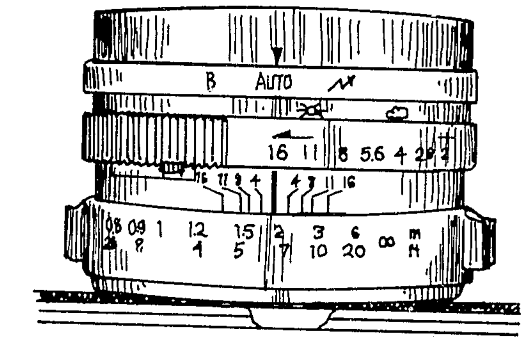


Figure 1.5.3.1-1

1.5.3.2 Lighting Conditions

Simple guidelines on lighting placement and conditions can make the difference between marginal and professional looking photographs. Where natural lighting conditions produce strong contrast between lighted areas and shadow areas, shadowed areas can be brought out by the use of the flash as a supplement even though there may be sufficient light for photography without the flash unit (4).

Most pictures should be taken with the lighting source, whether natural or artificial, coming from behind the camera and illuminating the scene. Side lighting should be avoided unless specific surface details, such as cracks, burn patterns, or vehicle tracks, need to be highlighted. Back lighting (light behind the subject) should be avoided.

Most light meters built into automatic cameras average the light being received. For this reason, if a building is photographed against a bright sky, the building will show up in deep shadow and details will be poor. Under these conditions, shoot the building at the normal setting and also at 1 or 2 "f" stops lower (wider opening). Most automatic cameras have some means for adjusting exposure or going to manual control. On other automatics, it is usually possible to aim the camera down at the ground (thereby reducing the amount of light reaching the meter), partially depressing the shutter button to lock the setting, then swinging the camera back up, aiming, and shooting. Alternatively, for these shots and when shooting flash shots in black on black interiors, the film speed dialed into the camera can be cut in half (a one-stop increase) or cut in half again (a two-stop increase). Remember to return the film speed dial back to its proper setting after you have finished.

1.5.3.3 Systematic Photography

Investigators should not fail to photograph even the least significant fire scene. The average cost to perform an investigation may range from $500.00 to $1,000.00, depending also upon the extent of laboratory tests. With the total cost per color slide amounting to about $0.25 in quantity, photography is an inexpensive investigative tool.

Each investigator should develop a systematic procedure for documenting a fire scene, logging each picture taken and recording the chain of evidence of debris removed. Shown in table 1.5.3.3-1 is a recommended systematic procedure for photographically documenting a fire investigation, whether the cause of the fire is accidental or incendiary in origin. This procedure is designed to produce a uniform and economical photographic technique based on the use of a 35 mm automatic camera, electronic flash and a sturdy tripod.

The first step is to document the exterior of the structure, vehicle or object before probing the cause of the fire. While encircling the structure, a quick field search can be made for additional evidence.

The second step is to document interior damage showing the extent and progress of the fire, including room(s), area(s), and point(s) of fire origin. These pictures are made before digging or probing the fire debris and will document the conditions upon the investigator's arrival.

The third step of the investigation concentrates on the debris clearing operations, the char and burn patterns, and the evidence prior to its removal from the fire scene. Should associated crimes, such as breaking and entering, theft, or homicide have taken place with the fire, any physical evidence of these criminal acts also should be photographed. Nothing should be moved, especially bodies of victims, until photographed and supported by crime scene notes. The scene also should be photographed after clearing operations.

Once an investigator has become familiar with the results and limitations of the camera, an attempt should be made to experiment with photography. Using a sturdy tripod, a series of overlapping photographs can be taken and later reconstructed with prints to form a mosaic view of the fire scene (see figure 1.5.3.3-9). Figure 1.5.3.3-10 shows the method by which the overlapping photographs can be taken from one camera position. Applications of this technique include the viewing of floors of large factories or warehouses. Note, however, that this technique should not replace the steps suggested earlier and displayed in table 1.5.3.3-1.

Table 1.5.3.3-1 Recommended Photographic Procedure for Fire Investigations

Step	Technique	Procedure	Example*
1	Exterior Photographs	Shoot a perimeter series of the subject.	Figure 1.5.3.3-1
2	Interior Photographs, Pre-clearance	Record photographic extent of fire damages.	Figure 1.5.3.3-2
		Photograph room(s) of fire origin.	Figure 1.5.3.3-3
		Photograph point(s) of fire origin.	Figure 1.5.3.3-4
3	Interior Photographs, Post-clearance	Photograph after clearing fire debris.	Figure 1.5.3.3-5
		Photograph evidence prior to removal from scene.	Figure 1.5.3.3-6
		Photograph characteristic burn and char patterns.	Figure 1.5.3.3-7
		Photograph packaged evidence submitted to lab	Figure 1.5.3.3-8
4	Mosaic Photographs	Use tripod to take overlapping series of photographs forming panoramic view.	Figure 1.5.3.3-9

*Located at the end of chapter 1.5.

1.5.4 Documentation

At the time of the investigation, a descriptive photographic index envelope, such as illustrated in figure 1.5.4-1, should be completed and kept with the exposed roll of film during and after processing. After development of the slides, selected views can be printed to be placed in the investigation report.

A mounting format for the attachment and documentation of photographs suitable for courtroom testimony or presentations may be used. Rubber cement is recommended for affixing the photograph to the paper. Should objections be raised in court, the photograph can be easily removed. Also, marks or writing should not be made on the photograph's surface unless requested during courtroom testimony.

The investigator also may wish to consider using an instant print camera for taking photographs at the fire scene. If one print does not show the desired detail, the investigator may immediately repeat the photograph.

1.5.5 Summary

Investigators should be trained to photographically document fire scenes using commercially-available 35 mm camera equipment. The investigator need not be an expert on the subject of photography, yet should have an understanding of the principle operational capabilities and limitations of the equipment.

Color slides are recommended as the most economical medium for photography, with color prints being made from selected views to document fire investigation reports and courtroom testimonies. Also, a systematic photographic sequence, similar to the one presented here, should be adopted by the investigator to insure a comprehensive documentation of the fire.

1.5.6 References

(1) J. D. Peige and C. E. Williams, Photography for the Fire Service. Stillwater, OK, International Fire Service Training Assoc., 1977.

(2) Basic Police Photography, Publication No. M-7. Rochester, NY, Eastman Kodak Co., 1968.

(3) P. R. Lyons, Techniques of Fire Photography. Boston, National Fire Protection Assoc., 1978.

(4) Fire and Arson Photography, Publication No. M-67. Rochester, NY, Eastman Kodak Co., 1971.

Figure 1.5.3.3-1

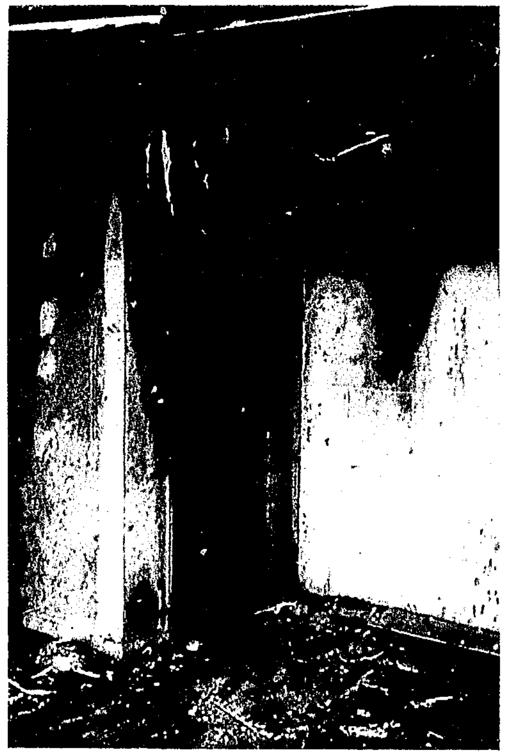


Figure 1.5.3.3-2

Figure 1.5.3.3-3

Figure 1.5.3.3-4

Figure 1.5.3.3-5

Figure 1.5.3.3-7

Figure 1.5.3.3-6

Figure 1.5.3.3-8

Figure 1.5.3.3-9

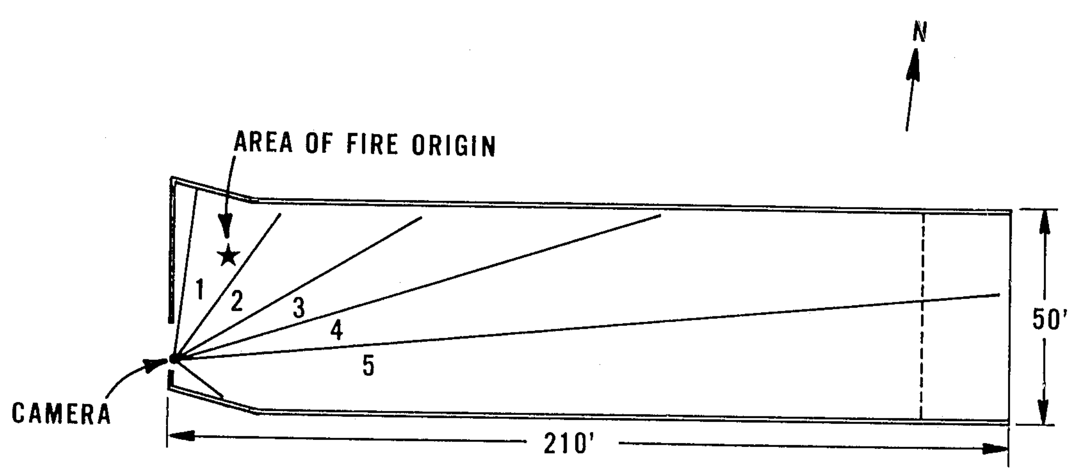


Figure 1.5.3.3-10

AB-9 OHIO STATE FIRE MARSHAL

Arson Bureau

CASE NO. ____________ OWNER ____________

ADDRESS (owner) ____________

ADDRESS OF FIRE ____________

DATE ____________

PHOTOGRAPHER ____________ WITNESS ____________

DATE PHOTOS TAKEN ________ TIME ________ WEATHER ________

MAKE OF CAMERA ____________ PROCESSED BY ____________

NUMBER OF PRINTS – 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

DESCRIPTION OF PRINTS	Distance	Direction	Light
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

SUBMITTED BY ____________

Figure 1.5.4-1 Photographic Index Envelop

1.6 FIRE INVESTIGATION RECORDKEEPING

1.6.1 Introduction

The types of information which should be included in any complete report on a fire incident is outlined. The most thorough and complete investigation is of little use if it is not properly documented. The following is only a guide and should be adjusted to meet local conditions. Readers should be cautioned that federal, state and local laws, as well as agency regulations, should be consulted in the development of any information system tailored for use within the jurisdiction.

The report is divided into two main parts: fill-in information and narrative. The narrative section has the subject matter for each paragraph spelled out to better facilitate any search for information. Remember: "The faintest ink is many times better than the best memory". If a fact is thought to be pertinent to the investigation, include it in your report.

1.6.2 Fill-in Information Sheet

This consists of prepared questions that may be on a preprinted form or on a cover sheet that contains the questions.

Fire Incident

- Month (written out)
- Date
- Year
- Day of week
- Time of day of fire (24-hour clock)

Investigation

- Month (written out)
- Date
- Year
- Day of week
- Time of day (24-hour clock)
- Investigation requested by
  - Date
  - Time (24-hour clock)

Incident Identification

- Fire Department incident number
- Investigation agency number
- Incident location:
  - Address:
    - Actual
    - Reported
      - Structure name
    - Fire Department or other area identification
- Type incident
- Weather conditions at time of incident; type, for example,
  - rain, snow, clear
- Wind
  - Velocity
  - Direction
- Temperature
  - °F or °C
- Relative humidity

Identification of Affected Persons

- Owner(s); occupant(s); victim(s):
  - Full name
  - Race (for NCIC, National Crime Information Center use)
  - Sex
  - Date of birth
  - Address
  - Phone numbers:
    - Home; work; other
  - Social Security Number (if volunteered)

Insurance Information (should be developed on all of the foregoing, as well as structure involved)

- Company Name
  - Address
  - Phone
- Broker's/Agent's Name
  - Address
  - Phone
- Adjustor's Name (if appropriate)

Type of coverage (fire, all-risk, etc.)
Limits and exclusions
Riders
Policy number(s)
Date of issue
Date of expiration
Date of increase or decrease in coverage
Policy payable to whom

Corporate Information

Name
Address; phone
Registered agent's name
Address; phone

Building (briefly)

Description
For example: 3 story, noncombustible with basement
Occupancy or use
for example, warehouse, T.V. shop, garden apt.
Condition of premises
Good, fair, poor (explain)
Contents
Typical
Not typical (explain)

Fire Point of Origin

Location
Probable equipment involved in ignition
Fire discovered by
Name
Address
Phone

Reported by
Name
Address
Phone

Probable cause (briefly)
Accidental (describe)
Incendiary (describe)
Undetermined (describe)

Structure:	Estimated value -	Estimated loss -
Contents:	Estimated value -	Estimated loss -
Total:	Estimated value -	Estimated loss -

Property
Released to
By
When Date Time (24-hour clock)

Witness(es)
Name
Address
Phone Number(s)
Age
Sex
Race

Final damage by
Adjusting bureau
Insurance company
Structure Contents

Referred to
Other agencies; for example, Police, Building Inspections, Highways

Photos taken by
Name
Agency
Date

1.6.3 Narrative Report

Paragraphs may be used "as is", or developed to best suit the needs of the individual investigator.

Paragraph 1 - Comments by on-scene investigator
Arrival - date and time (24-hour clock)

Observations
Flame color, smoke
Crowds
Unusual firefighting problems
Unusual conditions
Riots, demonstrations
Reported to
Officer in change
Comments and instructions

Record of preliminary interviews and volunteered statements.

Paragraph 2 - Statements

Records of in-depth interviews, statements, interrogations of owners
Occupants
Injured persons
Relations, friends, etc.
Behavior of occupants during fire emergency
Firefighters, police officers, others

Paragraph 3 - Building and occupancy description

Construction type
Occupancy use
Size of structure
Sketch of layout
History
Previous fires
Code violations
Financial condition

Paragraph 4 - Injuries and fatalities

Injuries
Name
Location and behavior of injured during fire emergency
Name of hospital
Extent
Type
Degree
Hospital or file identification number
Attending physician
Prognosis
Fatalities
Name
Location and behavior during fire emergency (if known)
Medical Examiner's report
Cause of death
Extent and type of injuries
Next-of-kin
Released to
Who discovered the victim?
How was the victim dressed?
Any unusual circumstances?

Paragraph 5 - Fire Scene

Point of origin - identification
1) Spread of fire
a) Patterns
b) Factors contributing to spread
c) Sketches and photos of
2) In-depth description of
a) Ignition source
b) First material ignited
c) Second material ignited
Conclusion(s)

Paragraph 6 - Smoke

1) Source, for example, wood, plastics
2) Type - light, medium, heavy
3) Contributing factors to smoke spread
Conclusion(s)

Paragraph 7 - Damage

Detailed description of damage
Fire/heat
Smoke
Water
Fire Department activity
Occupant activity
Other:
Utilities
Weather
Conclusion(s)

Paragraph 8 - Fire Protection Equipment

Type installed
Condition
Operational? If not, why?
Records of maintenance
Factor in fire situation?

Paragraph 9 - Utilities

Type on premises
Condition
Operational?
Factor in fire situation?
Building systems
Operational?

Paragraph 10 - Evidence

Collection by
Method; location (show on sketch)

Identification by
Method

Storage and preservation by
Method
Location

Chain of custody

Laboratory examination
Name
Address
Type of tests
Results

Paragraph 11 - Legal Actions

Incendiary fires
Persons arrested
Date
Records of prosecutions

Accidental fires
Court proceedings
Results

Paragraph 12 - Documentation to be attached to the narrative

Complete records of
Fire Department actions
Company and Battalion fire reports
Fire Alarm Headquarters reports
Investigations by other agencies
Medical Examiner's report
Records of evidence processing
Correspondence pertaining to incident
Legal documentation
Photographic records
Tapes and transcripts
Record of distribution of the report

1.7 ROLE OF THE FIREFIGHTER

1.7.1 Introduction

The role of the firefighter in fire investigations is to be observant. Upon arrival at the fire scene, the firefighters' first responsibilities are to rescue endangered persons and to confine and extinguish the fire. The firefighter's interest in the origin and cause of the fire must be secondary at this time, but that does not eliminate observation.

The first firefighters on the fire scene can be a valuable source of information to the fire investigator, particularly noting the fire's exact location, and its spread and intensification. Firefighters who have received training in the procedures and needs of fire investigations are especially valuable to the investigator. Trained firefighters know which details are important and which are not. The material in this chapter may be used as is. With appropriate additions it also could be the basis for a training program for fire suppression personnel or as training information.

1.7.2 What to Observe

The following are some of the observations a firefighter can make to assist the investigator. Not all of these will be used in every fire.

1) General fire scene conditions upon approach and arrival;

2) weather conditions, including wind speed and direction, and temperature;

3) automobiles or persons on foot leaving the fire scene (auto license numbers and descriptions of persons should be recorded, if possible);

4) smoke and flame colors at time of arrival;

5) the extent of involvement of the structure upon arrival;

6) exact location of initial attack;

7) bulk of the fire to the left, right, or straight ahead;

8) fire at the floor level, part way up the wall, overhead, or throughout the room;

9) the rapidity and direction of fire spread;

10) any unusual reactions when water is first applied;

11) any unusual odors or other signs of accelerants;

12) multiple fires with or without trailers between;

13) plants or fire starters which did not function (these should be carefully protected and preserved);

14) unusual wood charring or uneven burning;

15) holes in floors, walls, or ceilings, made before the fire;

16) windows open or closed and, if closed, whether locked;

17) doors open or closed and, if closed, whether locked;

18) any evidence or forced entry, burglary, or vandalism;

19) any evidence of tampering with fire protective systems, such as sprinkler systems (shut valves), fire detection and alarm systems, fire doors (blocked open), standpipes, fire extinguishers, and burglary systems;

20) any contents foreign to the occupancy (particularly those not indicated in the development of the pre-plan);

21) any contents missing which would be expected to be present (for example, missing clothing, empty closets, shelves, drawers, missing furniture, TV sets);

22) any evidence of tampering with the utilities such as, open gas cocks, broken gas piping, alteration of electrical equipment (to produce or enhance an ignition);

23) candles or remains thereof, matches or matchbooks (boxes) in the debris;

24) location of victims, if any.

1.7.3 During Overhaul

The fire investigation usually does not begin until the fire has been controlled and overhaul begins. During overhaul, it is vital that all evidence be preserved to the maximum extent possible. Delaying or minimizing the effects of overhaul, leaving contents in place, and avoiding trampling on or the destruction of objects all are extremely helpful to the investigator's reconstruction of the scene. During overhaul, water should be used conservatively to avoid destruction or dislodgement of evidence. The use of fog streams in recommended. Such precautions can ease the task the fire investigator faces in determining the fire cause.

Containers, which may have contained accelerants, should be left untouched and undisturbed to avoid smudging latent fingerprints. Gasoline-engine-driven fire department equipment, such as, chain saws and portable electric generator sets, should be refueled outside of the fire area to avoid gasoline spillage which could contaminate evidence of accelerants.

1.7.4 Additional Assistance to the Fire Investigator

With regards to the protection and preservation of evidence, it is preferable that only the investigator handle the evidence so that the chain-of-custody of evidence can be maintained. If evidence must be moved, the item and its exact location before removal should be recorded (photographs are helpful).

Firefighters should remember the variety and order of duties performed upon arrival. This will be of assistance to the investigator in establishing a chronology of events.

All statements made with regards to the fire should be made by the officer-in-charge. Even then, unless absolutely certain of the facts, it is best to refer all questions to the fire investigator. The rules of what actions make evidence inadmissable in court change frequently (see chapter 2.2).

Firefighters should make note of any information volunteered by persons at the fire scene and pass this information on to the investigator. If possible, the names, addresses, and telephone numbers of persons offering information should be included. However, the questioning of such persons by firefighters probably should be avoided (see chapter 2.2). Important questions, such as: "Is there anyone else in the building? Who is the owner? Are you the owner, tenant, etc.?" are not in this category. However, any doubt as to what questions can and cannot be asked should be discussed with the local prosecutor.

The investigator may be delayed in responding to the fire scene. If the fire department leaves the scene of the fire before the investigator arrives, an inadvertent break or discontinuity may occur in the fire department's control of the fire scene. Such a discontinuity may jeopardize the fire investigator's rightful access to the fire scene for purposes of the fire investigation. Therefore, it may be vital that the fire department remain in possession of the premises until the fire investigator arrives. Specific guidance on this point should be obtained from the local prosecutor and made part of the fire fighting procedures. (A recent example of where a warrant was required for the fire investigator's access to a fire scene due to a discontinuity in control of the fire scene between the fire suppression and the fire investigation is Michigan v Tyler, 436 US 499, 1978.)

2. Post-Fire Interviews

2.1 DEVELOPING INFORMATION FROM EYE-WITNESSES

2.1.1 Introduction

Interviewing people to obtain information about events they have witnessed has been described as a conversation with a purpose. During a post-fire interview, the purpose is to recreate as accurately as possible the fire under investigation through conversations with those who have firsthand information concerning the cause, point of origin and spread of the fire. Consequently, the present chapter will focus on the information-gathering interview; a two-person conversation, initiated by the interviewer for the specific purpose of obtaining relevant information.

2.1.2 Interview Sequence

While the interview may be considered a conversation between the interviewer and the respondent, the total interview process should include the following:

1) Create and select an interview format (questions, statements, pictures, or other meaningful stimuli that will produce the desired answers);

2) establish rules and procedures for using the interview format;

3) conduct the actual interview; evoke answers from witnesses that are of interest to the investigator;

4) record these answers by appropriate and available means (paper and pencil notes, sketches, recording equipment, etc.).

Step 1. In previous eyewitness research it has been found that respondents seem more accurate and detailed in their recall if the interview is begun in an open-ended way. The first question in the interview might be: "Can you tell me everything you know about the fire?" While such a question is intentionally broad, it allows respondents an opportunity to recreate the fire incident in their own words. Pointed questions at this time may lead respondents to report things that actually were not witnessed but were suggested by the

interviewer's remarks. The interviewer should show interest, be open, and be non-judgmental about everything reported by the witness. Interviewers should note appropriate points as the respondent is talking. These points can be pertinent information about the fire, as well as parts of the account that the interviewer may want to probe further in subsequent discussions.

Step 2. Once the respondent has recounted his/her version of the fire, the interviewer is able to move the conversation to a second stage. During this part of the process, the interviewer should take charge of the conversation. If the account rendered by the respondent seems complete and accurate, the interviewer may not feel a need to probe for further details. However, if the interviewer feels that the respondent could provide more details, or has inaccurately reported the fire (inconsistencies with previous interviews), further probes should be made. These can take the form of asking direct questions or simply asking for elaborations about various points of the respondent's narrative. At this time, the interviewer should not offer an opinion about the accuracy of the respondent's narrative account, nor suggest that the respondent intentionally is hiding information. If such is the actual case, the witness can be further examined in a subsequent session. If the interviewer appears as accusatory, any hope of making the account more accurate or complete may be lost.

Step 3. During the third step, specific questions should be asked that would be similar in every postfire session. These questions should be closed-ended, written in advance of the interviews, and produce simple but explicit, responses from respondents. Even if the points covered by these questions have already been covered by the witness, the interviewer should repeat the question to guarantee the reliability and standardization of responses to the closed-ended questions.

Step 4. The interviewer should conclude interview sessions by asking the respondent if there is anything else he/she would like to add to his/her responses. This final question is important, since the closed questions may have prompted rememberance of other details about the fire not previously reported. This final chance to add information will satisfy the need for witnesses to feel that they have been allowed ample opportunity to record their opinions, and at the same time frequently provides additional information to the interviewer.

2.1.3 Interview Techniques

The timing of the interview session is critical. In general, interviews should be conducted as soon as possible after the fire situation. This is not always possible. If people are extremely agitated, injured, or unavailable, the interval between the fire and the actual interview may be some hours or even days. With delays possible distortion may enter a witness's account. Also, as the witness tells the story again and again, unintentional elaborations and deletions appear which the witness begins to believe.

From the first contact, the witness must have confidence in the professionalism of the interviewer. First impressions are important. Politeness is critical in gaining an interviewee's cooperation.

The interviewer should be adaptable, friendly, and concerned in making the respondents as comfortable as possible. This is especially important for interviews after fires that have resulted in injuries or deaths. The open-ended format of the first stage of the interview is designed to encourage respondents to develop a more personal relationship with the interviewer. Respondents who initially are ill-at-ease may become relaxed by telling the account in their own words. If the respondent is relaxed, step two and three of the interview process are much more effectively accomplished.

2.1.4 How to do an Interview

The actual sequence of the interview is outlined in chapter 2.1.2. There are several points that bear repeating because of their importance. Interviewers should never imply that the witness is not telling the truth. Even if obvious distortions have crept into the narration, these should be gently qualified during step two of the interview process. If the respondent's trust in the interviewer-interviewee relationship falters, the validity of the entire process becomes questionable. The interviewer must convey the impression (which is in fact true) that the only knowledgeable people during the interview are the witnesses themselves. The sequence for the interview should be followed. While it is legitimate to probe for more details during step two of the process, the interviewer must be careful not to lead respondents according to the interviewer's own biases.

During step one, while respondents give open-ended accounts of the fires, the interviewer should communicate obvious understanding and interest in the respondent's narrative. Agreement by nodding, "Uh huh," and repetition of the respondent's key points are effective indicators of such interest. As the interview moves to steps two and three of the session and begins to probe for more detail, the interviewer should be certain that the respondent understands the sense of the question. Repetition of questions and adequate pauses to allow the respondent time to process the question and response are essential. If responses are incomplete, a pause frequently will produce more information from the respondent. The interviewer can guarantee that the answer is understood by repeating the answer according to the sense provided by the respondent. If the interviewer does not understand the answer, a neutral question like: "How do you mean that?" or, "Can you tell me more?", indicates to the respondent that while the answer might be on the right track, more information is desired.

Of importance during the interview is the interviewer's respect for the respondent. Sympathy for the difficulties related to replying about events that might be personally traumatic should be evident. The success of the interview is largely dependent on the amount of trust the interviewer can elicit from the respondent.

2.1.5 Recording of Responses

If absolute accuracy of the verbatim accounts of the witness is important, tape recordings of the entire interview session should be made. Frequently, however, verbatim accuracy is not essential. Do not transcribe such recordings as it is neither practical nor cost effective. Consequently, before deciding on the actual recording techniques to be used, the purpose of the interview and its stages must be clearly defined.

While electronic recording of the interview provides a reliable account, respondents can be intimidated by the presence of the recording device. Furthermore, some of what the respondent says is of no practical use to the post-fire investigation team. Long transcripts of the post-fire interview can inhibit recognition of the more salient and important details. Unless the fire is of special significance, electronic recording of the interview is not necessarily the most desirable procedure to use.

As indicated, each step of the interview process has its own goal: Step one, to allow respondents to refresh memories of the incident, and feel relaxed in discussing the fire; step two, to allow the interviewer an opportunity to probe incomplete or ambiguous parts of the narrative to obtain pertinent information; step three, to provide a reliable record of the respondent's report.

Methods of recording should correspond to the purposes of the individual steps of the interview process. During step one, the interviewer might make notes on the points to probe in step two of the interview. A few notes at this time can put the interviewee at ease as well as communicate interest on the part of the interviewer while, at the same time, providing reminders to the interviewer of points that need further elaboration. Step two of the process is more focused on information that is of particular importance to the post-fire investigation. Consequently, questions that the interviewer asks should be noted, and enough information recorded to provide a complete decipherable response to the intended questions. At this point, since reliability of responses is critical for post-fire comparisons, the respondent's answers should be repeated to verify their accuracy.

2.1.6 Summary

In general, the interviewer must win the trust of the respondent through sympathetic, non-judgmental and professional conduction of the interview. Three stages moving from open to closed ended segments are suggested for the post-fire interview to optimize accuracy and usefulness of respondent information. Recording of responses should be dependent on the purpose of the interview and each stage of the process.

2.2 LEGAL PROBLEMS

2.2.1 Introduction

Questioning a suspect can break open an arson case, but it can also destroy the case or lead to the questioner being sued.

2.2.2 Questioning Witnesses

Questioning individuals about a possible crime is a complex process, both psychologically and legally. The psychological components have been discussed in chapter 2.1. The legal problems are significantly different. Normally, the purpose of asking questions is to discover facts which the questioner does not know or is unsure of. In a criminal investigation the purpose may also include an attempt to convince a person who has committed a crime to admit to it, so that we can punish the person. Very early in our history, as part of the Bill of Rights, we established the principle that no person could be forced to testify against himself in a criminal case. This constitutional principle has been interpreted by the Supreme Court as prohibiting the introduction into criminal cases of involuntary confessions or any other evidence, of any sort, derived from an involuntary confession. The court also has laid down strict rules for what constitutes an involuntary confession. While there are some "grey areas", in the main the rules state that once an individual is "in custody" any questioning is suspect and the defendant must be given his/her "Miranda" (1)[1] rights before any interrogation. The "Miranda" rights are, in these words: (1) You have the right to remain silent. (2) Anything you say can and will be used against you in a court of law. (3) You are entitled to an attorney, prior to any questioning. (4) If you cannot afford an attorney, one will be appointed to assist you. If the suspect indicates at any time that he/she desires to invoke any of these rights, the questioning must cease.

The problem which faces the court most often is, "when is the suspect in custody". Custody is usually synonymous with being "under arrest". However, if you effectively prevent a person from leaving, he/she is probably "in custody" even if you do not have the power to legally arrest him/her. Therefore, the well-meaning fire officer, who

[1]Figures in parentheses refer to references at the end of the chapter.

apprehends a likely suspect on the scene, and starts questioning him/her, can hinder a subsequent prosecution, if it is based on a confession or other comments made by the suspect. In the fire service, the situation is complicated by several factors. First, some fire officers are given arrest powers, weapons and training in the interrogation of suspects. For all practical purposes, these people are police officers. Others are fire investigators, trained to investigate the technical causes and spread of fire. Still others are firefighters who have not had extensive training in fire investigation.

Firefighters generally should not conduct on-the-scene fire interviews except for the purpose of determining the possible extent of danger to persons or property, and securing from witnesses their names and addresses by a simple request. Under no circumstances should they order a suspect or anyone else to answer.

A firefighter's power to detain a suspect, which varies from state to state, is a two-edged sword since what might be a "voluntary" statement made by a suspect who is free to leave may become an inadmissable statement if made while in custody. The Miranda cases do not turn on the moment the investigator becomes convinced that a crime has been committed, but on the moment that a suspect is in custody. "In custody" is a very flexible concept.

The prosecutor and the local fire authority must have a reasonable understanding as to whether the prosecution of suspected arsonists or prompt determination of the cause of a fire without regard to prosecution is more important. It may be difficult to do both. If the fire service has already obtained inadmissable testimony, the State's case may be fatally weakened and it may not be possible to prosecute at all. In particular, it may not be possible to obtain testimony in return for immunity or plea bargaining if the evidence against the witness is tainted.

Fire investigators should carefully document all physical evidence before talking to potential suspects. In this manner, they can show that the evidence was not derived from a confession. "Voluntary", that is, non-custodial interrogation of a suspect is complex. In particular, the suspect must not be in any sort of restraint either by word or action. Normally, no "Miranda" warnings are given, but it is vital that no promises or threats be made to the suspect. Seemingly innocuous lines, such as "It will be better for you if you cooperate", can return to haunt the questioner. In addition the government bears a heavy burden of proving that any statement is "voluntary", even after "Miranda" warnings are given.

The problem is complicated by 42 USC 1983 which makes it a civil tort to deprive a person of a constitutional right under color of state law. Therefore, an official who claims legal authority to detain and question a suspect under a state law, which is in conflict with the United States Constitution, may be personally liable if a court finds the "constitutional rights" of the suspect have been violated.

Questioning witnesses also is legally significant. Particular care must be taken to avoid "coaching" the witness to produce the answers, that is, avoid asking questions which supply the answer to the witness. Particularly after a suspect has been apprehended, leading questions including a description of the suspect must be avoided, for example, "Did you see a limping white male, about 24 years old, run from the building?" Instead the questioner should bring out and record the actual statement of the witness without coaching. It is valuable, particularly in criminal cases, to take down verbatim statements of the witness, rather than mere answers to closed-end questions.

2.2.3 Summary

The investigation of the cause of a fire is a technical matter. When the investigation focuses on a particular person, complex legal questions arise. The investigator should be fully trained in the necessary legal aspects of the work.

The law of interrogation is both complex and constantly changing. The fire service must maintain constant contact with both the police and the prosecutor to ensure proper questioning in arson cases.

2.2.4 References

(1) Miranda v Arizona, 384 US 436, 86S.Ct.1602, 16L.Ed.2e 694 (1966).

3. The Building and Its Makeup

3.1 BUILDING CONSTRUCTION

3.1.1 Introduction

In many cases the design, construction, and use of the building contributes to the initiation and severity of serious building fires. For these reasons, a knowledge of buildings, how they are constructed, and with what kinds of materials, is important to the fire investigator.

A knowledge and use of the correct terminology of building construction also is important in the writing of accurate reports, as well as in courtroom appearances. As an example, the investigator should know and be able to describe the similarities and the differences between spandrels, beams, and girders.

Sometimes in getting at the fire cause, it is necessary to "reconstruct" the arrangement and condition of the room or area of fire involvement to understand the development and spread of the fire. To do this "reconstruct", it is necessary to know what kinds of building materials and construction were likely to have been present prior to the fire damage. (Where there are similar rooms or areas available in the same or similar buildings, such as in hotels or garden apartments, a method to "reconstruct" is to examine undamaged units.)

3.1.2 General Construction Principles

The fire investigator should be familiar with the basic principles of building construction. A brief summary of F. L. Brannigan's Building Construction for the Fire Services (1)[1], chapter 2, is presented.

> The initial concern of fire resistance provisions in building codes is that the building should not collapse as a result of a fire. Secondarily, the structure should limit the fire to an area of acceptable size.

[1]Figures in parentheses refer to references at the end of the chapter.

Some elements of the system are more vulnerable to fire than others. When a fire occurs, the building is only as stable as the weakest (to fire) element.

All loads must be transmitted continuously to ground. This is accomplished by a multitude of structural components and connections in the structure. The importance of the connections varies. In some cases, the failure of a connection may have only a local effect. In other cases, the failure may be catastrophic in that a building collapse may occur.

Principal structural materials are wood, masonry (stone, brick, and concrete block), steel and reinforced concrete.

The principal elements of structures are walls, columns, and beams. Walls and columns carry the loads of the building down to the earth. Beams carry the loads generated on each floor of the building to the columns or walls.

Walls may be load-bearing, that is, carrying a load other than themselves, or be nonload-bearing, typically partitions and exterior veneer walls.

Columns carry vertical loads to the ground or foundation. Because columns take up space, suspension rods or cables in tension are sometimes used to "hang" certain loads in a building. The system must, however, provide for the tensile load to be carried over into a column or wall and delivered to the earth in compression.

Floors and roofs are supported on beams and girders as well as on walls. A girder is a beam which supports other beams. Since beams must resist both tension (usually in the bottom of the beam) and compression forces (usually in the top), solid beams contain excess material. In many cases, the load can be carried on a lighter unit called a truss, which eliminates excess material. A trussconsists of a series of specially connected and designed load-carrying elements and open spaces, which makes it more vulnerable to fire and thus more likely to collapse than an equivalent solid beam.

3.1.3 Types of Building Construction

There are five basic construction types (2). Various building codes subdivide these types further (see table 3.1.3-1). The five types are:

Table 3.1.3-1 Types of Construction According to Model Codes*

Construction Type	Basic Building Code, by Type (BOCA)	Standard Building Code, by Type (SBC)	Uniform Building Code, by Type (UBC)	National Building Code, by Type (NBC)
Fire Resistive	1A 1B	I II	I	A B
Noncombustible Protected	2A 2B	IV (1 hr)	II (4 hr) II (1 hr)	Protected Noncombustible
Noncombustible Unprotected	2C	IV	II (N)	Unprotected Noncombustible
Heavy Timber	3A	III	IV (HT)	Heavy Timber
Ordinary Protected	3B	V (1 hr)	III (1 hr)	
Ordinary Unprotected	3C	V	III (N)	Ordinary
Wood Frame Protected	4A	VI (1 hr)	V (1 hr)	
Wood Frame Unprotected	4B	VI	V (N)	Wood Frame

*This table indicates the "type" assigned by the respective codes to various construction types. It is not intended to indicate that different codes necessarily have identical requirements for any specific type.

Fire Resistive
Noncombustible
Heavy Timber
Ordinary
Wood Frame

The investigator's report should use the terminology of the appropriate local code.

Note that the commonly used word "fireproof" does not appear in the list of types, though it may appear in some codes. When designers first considered fire as a problem they believed that all fire problems would be eliminated by constructing the building of noncombustible material. Such buildings were called "fireproof" and the misnomer has persisted. Early "fireproof" buildings were found deficient when put to the test of actual fires since all noncombustible materials will lose strength at sufficiently high temperatures. As technology improved, the term "fire resistive" emerged.

Fire Resistive buildings are ones in which specimens of the major structural components have been rated by standard fire endurance tests during which collapse and passage of fire, where appropriate, were resisted for prescribed periods of time. No direct relationship should be assumed between the "time" of the controlled test and an uncontrolled hostile fire. Whereas each of the elements of the building may meet fire resistance criteria, it is most unlikely that the building as a whole was ever analyzed for the total impact of a potential fire, and "the whole may be less than the sum of the parts". Fire resistance does not guarantee life safety. Fire resistance is not necessarily related to fire loss; in fact, while achieving its designed fire resistance, the structure may be damaged severely. Fire resistive assemblies are not necessarily noncombustible. Floors and walls of wood and gypsum board are assigned fire resistance ratings by UL (Underwriters Laboratories Inc.), even though the assemblies are combustible.

Depending upon how the fire resistance is achieved, different buildings of the same fire resistance rating may exhibit different characteristics in similar fires. For instance, a fire resistive floor of reinforced concrete absorbs considerable heat. A steel joist floor and ceiling assembly, of equal fire resistance, will not absorb as much heat. This can affect the propagation of a fire, as every Btu absorbed by the structure is one less available to keep the fire growing. As a second example, a rated reinforced concrete floor may act as a very effective smoke barrier. An equally rated floor and ceiling assembly with an integral air handling system could provide a path for travel of smoke and gases. This property is not considered in the test rating.

Noncombustible buildings are ones in which the walls, partitions and structural members are of noncombustible construction not qualifying as fire resistive construction.

Heavy Timber Construction buildings have masonry exterior walls and heavy timber interiors. The concept is that the heavy timber is slow to ignite and burns at a slow enough rate that collapse may be delayed. The concept fails once the fire involves the building and the fire suppression forces cannot sustain an interior attack. The massive amount of timber then simply becomes a tremendous fire load.

Ordinary Construction buildings have masonry exterior walls and lightly constructed combustible interiors. The principal benefit of the masonry walls is to reduce the conflagration potential. The interior is expected to collapse in a fire and may be required by code to be so designed, the so-called fire cuts on wood joists are an example.

Wood Frame buildings are basically of wood construction. A noncombustible veneer, such as brick, does not change the nature or classification of the building.

3.1.4 Building Materials and Contents

Code regulations which limit the type and size of construction are predicated on the type of building, the type of occupancy anticipated, and the anticipated level of potential fire risk. Estimates of the potential fire risk are based to a large extent on the fire load (or fuel load). For buildings of combustible construction the basic fire load is the building itself, thus such buildings are usually limited by code in area and height. In addition, for all buildings the weight of combustible contents per unit of floor area must be considered. Fire loads are usually expressed in the term pounds (of ordinary combustibles) per square foot. All weights are commonly converted to the equivalent of ordinary combustibles such as wood which has a heat value of about 8,000 Btu/lb. For instance, plastics which have a heat value of about 16,000 Btu/lb are converted at the rate of 1 lb of plastic to 2 lb ordinary combustibles. The potential heat value of many common fuels are given in tables of "calorific value" (see table 5.3.6-1 for examples).

Typical ranges of fire loads for the more common occupancy classes are shown in table 3.1.4-1. However, fire loads can vary considerably according to the occupancy, the specific location in the building, and other factors.

Table 3.1.4-1 Typical Fire Loads

Occupancy Classification	Typical Range of Fire Loads lb/sq ft
Residential	5 to 10
Educational (Library)	5 to 10 (10 to 40)
Institutional	3 to 10
Assembly	5 to 10
Business (office) (File, Storage)	5 to 10 (10 to 40)
Mercantile	10 to 20
Industrial	10 to 35
Storage	10 to 100
Hazardous	*

*No typical values available. Risk based on factors other than fire load.

Source: Fire Resistance Classification of Building Construction. Report BMS 92. October 7, 1942. Combustible Contents in Buildings. Report BMS 149. July 25, 1957. Washington, DC, National Bureau of Standards (US).

Structural fire protection requirements in building codes are based on fire resistance or fire endurance ratings expressed in hours. The ratings are based on fire tests performed on the structural or compartmenting (separating) building components according to the NFPA 251 (ASTM E 119) standardized test procedure (4). The exposure is such that a temperature of 1000°F (538°C) is reached in 5 min, 1700°F (927°C) in 1 hr, 1850°F (1010°C) in 2 hrs, 2000°F (1093°C) in 4 hrs and 2300°F (1260°C) in 8 hrs. These temperatures-vs.-time points produce a curve which is referred to as the fire endurance standard time-temperature curve. The test is conducted in a special test furnace, and continued until one of several criteria of failure, as appropriate, is reached: (a) structural failure (inability to sustain the applied load), (b) integrity failure (development of a crack or opening through which flames or hot gases may pass during the fire test, or a hose stream test) or, (c) insulation failure (heat transmission sufficient to raise the temperature on the unexposed surface by 250°F (139°C) average).

Although the standard fire test curve represents only one type of fire exposure, it serves as a useful means for the comparative rating of individual columns, beams, walls, partitions, and floor and ceiling assemblies. Again, it should be stressed that although the ratings are expressed in hours, the relationship between the rating hours and hours of an actual fire assault on a building may differ.

A relationship between fire load and equivalent fire endurance period was developed many years ago based on experimental burnouts of combustibles in special masonry test buildings and is shown in table 3.1.4-2. Table 3.1.4-2 indicates that the burning of a fire load of 10 lbs of ordinary combustibles per square foot (or 80,000 Btu/sq ft) is the approximate equivalent of 1 hour of the standard fire test ASTM E 119.

If these figures are used cautiously and broadly, rather than precisely, it is possible to estimate whether, in a given fire, the fire load was grossly excessive for the fire resistance of the building. Consider a building with floors rated two-hour fire-resistive. Such a building might reasonably be expected to successfully resist a fire involving a design fire load of 160,000 Btu/sq ft average. On the other hand, an investigator may estimate that in the affected area of an actual fire, the fire load was 300,000 Btu/sq ft average. It can be reasonably concluded that the fire area was overloaded from the fire endurance point of view, even though the total structural loading may have been within permissible limits.

Table 3.1.4-2 Fire Load versus Equivalent Fire Endurance Period in Standard Fire Test

Fire Load lb/sq ft	Equivalent Fire Endurance Period hr
5	1/2
7-1/2	3/4
10	1
15	1-1/2
20	2
30	3
40	4-1/2
50	6
60	7-1/2

Source: Fire Resistance Classification of Building Construction. Report BMS 92. October 7, 1942. Washington, DC, National Bureau of Standards (US).

Structural members and floors are made fire resistive in a variety of ways.

Reinforced concrete has inherent fire resistance. This inherent fire resistance can be increased to the desired level by increasing the concrete cover over the "reinforcing" steel. If the depth of the concrete cover is not as specified, early failure may result.

Steel must be protected from the harmful effects of elevated temperatures (loss of strength, elongation and heat transmission). Protection can be accomplished in several ways, including encasement, sprayed fireproofing, membrane protection or by using water-filled columns. In a particular building more than one way may be used.

Encasement. Each structural steel member is encased in an insulating cover; hollow tile, poured concrete, concrete block, wire lath and plaster or gypsum board are typically used.

Sprayed "Fireproofing". In this case structural steel members are sprayed or troweled with plaster containing inorganic fibers or cement. One common material formerly used, asbestos, is held responsible for health hazards due to inhalation in many buildings. In some cases this has caused its removal, sometimes without any provision for replacing the necessary fire resistance. Sprayed "fireproofing" may be poorly done and in many cases is found to have fallen off or been removed by other building trades.

Membrane Protection. Large areas, such as entire floors, are protected by a membrane, consisting typically of a wire lath and plaster ceiling or a suspended ceiling of individual panels. The problem is that, like all membranes, a single penetration may reduce the effectiveness of the entire membrane. Wire lath and plaster membranes are designed to be permanent and generally left in place but individual acoustical tile (panel) ceilings are readily removable.

The entire floor and ceiling assembly is fire rated as a unit. The presumption is that the unit is installed the same way as the unit tested. Even if this is accomplished, the ceiling tiles may be removed for many reasons. The fact that the ceiling tiles are part of the fire resistance of the building is unknown to many building owners and operators and fire inspectors. Untested penetrations as for sound system speakers are another weakness. Any tampering with the ceiling opens the entire floor area up to attack by fire. The void space between the ceiling and the floor above represents a potential for lateral fire spread between every floor of the building. There can be a substantial fire load in the void due to plastic insulation and piping, and light-weight merchandise is sometimes found stored in the void.

In one case, fire in one occupancy entered the void and extended downward to combustible shelves and contents in the next occupancy (5). This was detected early enough to clearly show what had happened. Had the extension not been detected, all appearances would have been of two separate fires. In fact, the fire was incendiary and successfully prosecuted. Failure to describe the development of the fire accurately might have led to a loss of the case.

Current lists of fire rated constructions and assemblies are maintained by Underwriters Laboratories (6), the American Insurance Association (7), and the Factory Mutual System (8).

Almost any structure has some degree of fire resistance, even though it is itself combustible. Table 3.1.4-3 is provided to enable the investigator to develop estimated fire resistance values for some common wall and floor assemblies. It consists of two parts. In the first part values are given for some common materials used as membranes (the surface finish). The second part gives values for framing members.

For example, using table 3.1.4-3, unprotected open web steel joists are assigned a value of 7 minutes. With 1/2" gypsum wallboard properly attached and sealed, the combination could be assigned a time of 22 minutes (7 minutes for the steel joists, 15 minutes for the gypsum wallboard).

A wood stud wall with 1/2" gypsum board on both sides could be assigned a value of 50 minutes (20 minutes for the studs plus 15 minutes for each layer of the wallboard).

It should be stated here again that the times referred to are estimates of how long the structure in question would continue to meet the standards of ASTM E 119 (NFPA 251) when tested in accordance with that standard. There is no necessary relationship to elapsed time in a hostile fire.

Table 3.1.4-3 Time Assigned to Wallboard Membranes

Description of Finish	Time Assigned to Membrane in Minutes
(i) 1/2 in Fiberboard	5
(ii) 3/8 in Douglas Fir Plywood phenolic bonded	5
(iii) 1/2 in Douglas Fir Plywood phenolic bonded	10
(iv) 5/8 in Douglas Fir Plywood phenolic bonded	15
(v) 3/8 in Gypsum Wallboard	10
(vi) 1/2 in Gypsum Wallboard	15
(vii) 5/8 in Gypsum Wallboard	30
(viii) Double 3/8 in Gypsum Wallboard	25
(ix) 1/2 + 3/8 in Gypsum Wallboard	35
(x) Double 1/2 in Gypsum Wallboard	50(1)
(xi) 3/16 in Asb. Cem. + 3/8 in Gypsum Wallboard	40(2)
(xii) 3/16 in Asb. Cem. + 1/2 in Gypsum Wallboard	50(2)
(xiii) Composite 1/8 in Asb. Cem. 7/16 in Fibreboard	20

(1)No. 16 s.w.g. 1 in sq wire mesh must be fastened between the two sheets of wallboard.
(2)Values shown apply to walls only.

Time Assigned for Contribution of Wood or Light Steel Frame

Description of Frame	Time Assigned to Frame in Minutes
(i) Wood Stud Walls	20
(ii) Steel Stud Walls	10
(iii) Wood Joist Floors and Roofs	10
(iv) Open Web Steel Joist Floors and Roofs	10(07)*

*Lower value based on work noted in the National Bureau of Standards' Report BMS 141.

Source: Fire Performance Ratings, 1965. Supplement No. 2 to be National Building Code of Ottawa, Canada, 1965.

3.1.5 Building Code Requirements

In many cases a building is not required by code to be fire resistive but the designer chooses to use components which resemble rated fire resistive units (or which may in fact be rated). For instance, structures recently observed in the Washington, DC area are rated as Type 3C (unprotected ordinary) under the BOCA (Building Officials and Code Administrator's International, Inc.) Basic Building Code. The floors are of bar joist construction with concrete topping on corrugated metal. The suspended ceilings need only meet Fire Hazard (flame spread) requirements. When the job is finished its appearance will be similar to a rated floor and ceiling assembly and protected with the same surface finish. Wood joists would have been acceptable under the code and the floor as installed may not be as resistive to collapse as a wood joisted floor.

In a fire investigation it may be necessary to determine whether or not a fire-resistive structure or structural element reacted to the fire in a manner consistent with its rating. This can be extraordinarily difficult.

Assuming that the building was required to meet fire resistance standards, there can be several reasons for determination of the reason for failure to perform adequately. Information developed may be of use in prosecution, civil actions, code changes or fire suppression planning.

Did the building meet code requirements? This requires a thorough knowledge of code requirements at the time the building was built and access to original drawings, change orders and officially authorized variances.

Possibly, in fact, the building met modern code requirements but when given the ultimate test, the fire, the code requirements were proven inadequate. Such information, properly developed and carefully documented, is vital to translating costly experience into recommended code revisions.

Valuable information also can be developed to aid fire suppression forces in preplanning and combating future fires in the same or similar buildings. For example, the investigation may develop information that the sealant of the floor slab to the panel exterior walls was made of foamed plastic which lacks "dimensional stability" (that is, it melts). If this was permitted in one building, it may exist in other buildings built about the same time.

3.1.6 Involvement of Ceilings

Fires generally burn upward. Thus, the ceilings and upper parts of walls are generally exposed to higher temperatures than the lower parts of walls and floors. Fire exposed ceilings can fail early in fires, sometimes considerably earlier than a fire test rating would indicate.

The fact that a particular ceiling fell may be an important element in an investigation. It cannot be assumed that the ceiling stayed in place for as long as one might conclude from its quoted fire rating.

Recently there have been a number of cases of fires burning downward (10). Many plastics when ignited form a pool of fire on the floor. The plastic may be from building contents or it may have been installed as part of the wall or ceiling.

Material falling from the ceiling may extend the fire beyond the area of origin. Consider a noncombustible building with steel bar joists with combustible tile ceiling mounted on the bottom side of the joists. There is a gap atop the masonry partition wall equal to the height of the top chord of the joist. Heated gases passing through this gap into the adjacent space may ignite the combustible tiles on their upper side. They may fall, extending the fire beyond the masonry wall.

3.1.7 Building Elements

Historically the chief consideration in building fire problems has been given to the Structural Elements of the building, but in building fires three elements can be identified:

- Structural Elements
- Nonstructural Elements
- Contents

The structural elements are those which are necessary to the stability of the building. The nonstructural elements may be more important in the development and extension of a fire than the structural elements. Nonstructural elements which contribute to the fire are independent of the type of construction and may be found in any of the five structural types discussed in chapter 3.1.3. For instance, a high flame spread interior finish of plywood and fiber tile may be found in any type building. The life hazard due to rapid flame spread over the surface will be the same. In the case of a combustible building the interior finish may be the kindling which ignites the structure. In the case of a noncombustible or fire-resistive structure, the structure will not be ignited, but substantial damage may be done to structural elements.

Nonstructural elements can include the electrical system, interior finish on ceilings, walls, and floors, air handling systems, openings from floor to floor such as shafts, stairways, interior courts, and combustible exterior surfaces and insulation.

In the majority of fires the initial fuel is the contents. Only rarely is the building directly ignited. (See chapter 3.1.4.)

3.1.8 Interior Finish

Up to World War II there was only one significant interior finish, plaster installed over either wood lath or metal lath. It is noncombustible and, when properly installed, provides a degree of fire resistance for combustible structural elements. If the plaster is penetrated and if wood lath is present, the wood lath may provide substantial fuel.

The interior finish of the building may be the most important single element in the development and spread of a fire. In a number of cases interior finish has been a major factor in the rapid spread of fire and resultant loss of life (10).

Interior finish may be applied to the ceiling, walls or floors. Building codes have applied specific limitations on the flame spread classification of wall and ceiling materials. Floor coverings are less likely to be regulated but flame spread over carpeting, for example, has been an important factor in a number of serious fires. Standards and techniques for measuring carpeting flame spread have been developed recently and these regulations have begun to appear in the codes (11,12).

There are a number of ways in which the restriction of high flame spread interior finishes can be circumvented which do not appear in the code regulations. Materials which would not be permitted by the code if attached to the building may appear in significant amounts as furniture, in exhibits, as free standing office dividers, and in merchandise displays.

Alterations are sometimes accomplished without a building permit and buildings properly built have been altered with the use of high flame spread ceiling or wall materials.

Even the building permit does not guarantee safety. Consider a building with a combustible acoustical tile ceiling. It is planned to "modernize" the room by installing a ceiling grid with tiles and light fixtures mounted below the existing ceiling. A local code may require the new tiles to meet flame spread requirements but there is no requirement to remove the old combustible ceiling hidden in the void. Such a hidden ceiling can generate heat and gases which can move upward through available openings.

The investigator must try to get an accurate description of the wall and ceiling surfaces before the fire. Often only very slight clues are available, for example, nails holding scraps of furring strip to joists may indicate that there was a combustible acoustical ceiling. Adhesive beading on a wall may indicate where paneling had been secured with adhesive. Small pieces may be found behind unburned baseboard.

Table 3.1.8-1 contains a listing of selected materials commonly used for interior finish in buildings and a rough classification according to flame spread rating by ASTM E 84 (9). This tabulation is intended only as a general guide and the reader should not assume that

Table 3.1.8-1 Approximate Flame Spread Ratings (E 84 Tunnel Test)

Ceilings	
Gypsum Plaster	0
Sprayed mineral-base plaster	0 - 20
Enameled metal	0 - 20
Mineral fiber tile	10 - 25
Glass or mineral fiber board or tile, coated	10 - 40
Wood-base acoustical tile (flame proofed)	20 - 75
Wood-base acoustical tile (untreated)	75 - 300
Walls	
Brick, concrete, asbestos-cement board, ceramic tile, gypsum plaster	0
Enameled steel, aluminum	0 - 20
Gypsum board, various facings	10 - 50
Wood, fiberboard (flame-retardant treated)	20 - 75
Plastic Paneling (flame-retardant treated)	20 - 75
Wood, at least 0.5 in thick, various species	70 - 200
Plywood paneling	70 - 300
Hardboard	100 - 250
Cork	200 - 500
Cloth, paper, wood veneer, fiberboard (untreated)	200 - 500
Shellac finish on wood	500+
Floors*	
Concrete, terrazzo	0
Vinyl Asbestos Tile	10 - 50
Red oak	100
Linoleum	100 - 300
Carpeting**	50 - 600

*Use of E 84 Tunnel Test on Floor Covering Materials is no longer recommended. See other test methods, for example, NFPA 253 (12) and ASTM E 648 (16).

**Depends on type of face fiber, underlayment, method of attachment if glued down, loose, etc.

all materials of the same generic type will perform in a similar manner. Furthermore, although a flame spread classification rating or label denotes that a test has been performed on a sample of the material, there is no assurance that the material will not contribute in a major way to the spread of a fire in an actual building situation. A fire investigator should not hesitate to request that tests be performed on samples of unburned material removed from the building where the finish material appears to have contributed significantly to the fire.

In removing materials for testing the investigator should understand how the test is done so that proper samples will be obtained. If it is possible that criminal proceedings will develop, the samples must be treated as any other criminal evidence.

ASTM E 84 (9), the Steiner Tunnel Test, is the usual basis for legal regulation of flame spread. The sample required is about 22 in width and 24 ft (565 mm x 7.32 m) in length. It may not be easy to get a sample of this size, but it may be necessary.

The fact that the method of attachment is important to the actual flame spread of combustible tiles was discovered when a full size sample of tiles glued to gypsum board showed a much greater flame spread than the same tiles, removed from the board for shipment (13).

ASTM E 162 (15) requires a sample only 6 x 18 in (15 x 46 cm). Samples this size are easier to get. For some materials, results from this test can be correlated in a general way with ASTM E 84 (9) but no direct relationship should be assumed. The information developed can be useful in developing better code requirements. If the question of discrepancy in the installed material is going to be criminally significant, the prosecutor should be made aware of the difference in these tests because it might be critical to the case that the test be performed under the same conditions as the code requires, which would almost invariably be ASTM E 84.

Carpeting should first be tested to the requirements of FF 1-70 (11), also known as the "pill test". The "pill test" only measures the ignitability of the carpet from small flame sources, such as a dropped, burning match. If the carpet passed the "pill test", and it was thought to have contributed significantly to the fire, it may be useful to test the flame spread properties of the carpet, properties which are not involved in the "pill test". One flame spread test procedure is that given in NFPA 253, Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source (12,16). For this test, samples 10 x 42 in (25 x 107 cm) are required. If a pad was used with the carpet, this pad should be included with the carpet in the test.

Nearly all carpets will spread fire if the exposure is sufficiently intense. However, some carpets spread fire under less heat exposure than others. If a pad is used under a carpet, the pad generally will cause an increase in the carpet's flame spread characteristics. The purpose of conducting the NFPA 253 test is to determine whether the carpet spreads fire easily or is more resistant to this spread than other carpets. The results of NFPA 253 will be a number called the critical radiant flux (CRF). To compare this number against other carpets, one should then refer to reference (14) which lists the CRF's for many different types of carpets, with and without padding.

3.1.9 References

(1) Brannigan, F. L., Building Construction for the Fire Service. Boston, National Fire Protection Assoc., 1971.

(2) Standard Types of Building Construction. NFPA No. 220-1975. Boston, National Fire Protection Assoc., 1975.

(3) Fire Protection Handbook, 14th ed., Table 3-11H. Boston, National Fire Protection Assoc., 1976.

(4) Standard Methods of Fire Tests of Building Construction and Materials. NFPA No. 251-1972. Boston, National Fire Protection Assoc., 1972.

(5) Brannigan, F. L., Fire Spread Through Noncombustible Concealed Spaces. Fire Journal, Vol. 63, No. 4, pp. 14-16, July 1969.

(6) Fire Resistance Index, 1979. Chicago, Underwriters Laboratories, Inc., 1979.

(7) Fire Resistance Ratings. New York, American Insurance Association, 1964.

(8) Approval Guide. Norwood, MA, Factory Mutual System, 1979.

(9) Standard Method of Test for Surface Burning Characteristics, ASTM E 84. Philadelphia, PA, American Society for Testing and Materials, 1978.

(10) Brannigan, F. L., Fire Hazards in the Construction of Garden Apartments and Townhouses. Boston, National Fire Protection Assoc., 1976.

(11) Standard for the Surface Flammability of Carpets and Rugs (FF 1-70). Federal Register, Vol. 35, No. 74, p. 6211, April 16, 1970.

(12) Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source. NFPA 253-1978. Boston, National Fire Protection Assoc., 1978.

(13) Juillerat, E. E., Jr., The Hartford Hospital Fire. NFPA Quarterly, Vol. 55, No. 3, pp. 295-303, January 1962.

(14) Benjamin, I. A. and Adams, C. H., The Flooring Radiant Panel Test and Proposed Criteria. Fire Journal, Vol. 70, No. 2, pp. 63-70, March 1976.

(15) Standard Method of Test for Surface Flammability of Materials Using a Radiant Heat Energy Source, ASTM E 162. Philadelphia, PA, American Society for Testing Materials, 1978.

(16) Standard Method of Test for Critical Radiant Flux of Floor Covering Systems Using a Radiant Energy Source, ASTM E 648. Philadelphia, PA, American Society for Testing Materials, 1978.

3.2 MATERIALS

3.2.1 Introduction

Knowledge of the effect of fire and high temperature on all types of materials -- construction, interior finish, furnishings and contents -- is essential to the job of the fire investigator. In searching through a burned building, the investigator should make note of the materials which were relatively unaffected as well as those which burned, charred and melted. The historical patterns of fires in buildings should be recognized and comparative differences or similarities noted.

3.2.2 Properties of Materials

There are many properties of materials which determine their response to fire and high temperature, as well as the contribution they may make to the growth of a fire. The principal fire properties of organic materials are heat of combustion (chapter 5.3.6) and ignition temperature (chapters 3.2.3, 4.6.6, 5.3.3, 5.5.2). Other thermal and mechanical properties include heat conductivity, specific heat (heat absorption capacity), melting and softening points, coefficient of expansion (elongation due to heating), shrinkage, cracking, etc. Some typical thermal properties are listed in table 3.2.2-1.

The high thermal conductivity of metals can be a means of spreading fire, for example, through sheets, ducts, joints, connectors and fasteners. Specific heat (or more accurately volumetric heat capacity) is a measure of the capacity to absorb and store heat. A material with a high heat capacity will heat up slower and may keep the maximum air temperatures lower but it will also retain the heat longer. Where high temperatures exists, thermal radiation is important and shiny surfaces (aluminum, steel, mirrors) may reflect the heat to other surfaces. While reflective surfaces would be expected to remain cooler, in most cases smoke deposition, oxidation and other changes often occur on shiny surfaces so that they

Table 3.2.2-1 Typical Thermal Properties of Selected Materials

Materials	Density Lbs/Cu Ft	Thermal Conductivity[1] Btu-in / hr ft^2 °F	Specific Heat[2] Btu/lb °F	Percent Increase in Length for Each 100°F Temp Rise	Melting Point °F
Air	0.06	0.2	0.24		
Water	62	5	1.0	0.01	32
Aluminum	165	1400	0.22	0.14	1220
Brass	530	720	0.09	0.11	1650
Copper	560	2600	0.09	0.09	1980
Cast iron	440	320	0.13	0.06	2466-2550
Steel	490	310	0.12	0.06-0.15[3]	2370-2550
Glass	160	6	0.20	0.04-0.06	2600
Brick	120	5	0.22	0.05	-
Concrete, normal weight	140	9-12	0.16-0.25	0.06-0.08	-
Asbestos-cement board	120	4	0.2		
Wood (oak, maple)	45	1.1	0.30-0.55	0.03-0.05	-
Wood (fir, pine)	32	0.8	0.33-0.45	0.02-0.03	-
Hardboard	65	1.0	0.33	-	-
Plywood	35	0.8	0.29	-	-
Fiberboard (wood or cane)	15	0.35	0.30	-	-
Plaster	70	3-6	0.23	-	-
Gypsum Board	50-60	1.5	0.26	-	-
Glass fiber batt	0.6	0.5	0.2	-	-
	3	0.3	0.2	-	-
Mineral wool	3	0.3	0.25	-	-
Plastics, rigid					
vinyls	-	1-2	0.2-0.3	0.3-1.0	-
styrene	-	0.7-1.0	0.32-0.35	0.3-0.4	-
Polystyrene foam	2	0.26	0.32	0.3-0.4	-
Polyurethane foam	2	0.18	0.38	0.4	-

Note: Values listed are estimated values at ordinary temperatures, or over typical temperature ranges in fires, if available. Actual values vary considerably with temperature, particularly where moisture is involved.

[1] The number of Btu transmitted in one hour, through one square foot, one inch thick, for each degree of temperature difference.

[2] Specific Heat is the number of Btu required to increase the temperature of one pound of the material one degree F.

[3] Steel elongation increases at higher temperatures.

eventually absorb as well as most other materials. Melting and softening points are obvious indicators of fire scene temperatures, provided allowance is made for fallen ceilings (which may protect materials at floor level), heat sinks (metals, for example, or water) and exposure to heat prior to the fire.

3.2.3 Classes of Materials

Detailed information on the effect of heat on specific materials is available in specialized textbooks and reference books (for example, Flammability Handbook for Plastics by C. J. Hilado, 2nd ed., Westport, CT, Technomic Publishing Co., 1974). The following information is provided as an abbreviated guide to selected materials for field reference.

Masonry. In common usage, this term includes precast or cast-in-place concrete, concrete and cinder block, brick, stone, cement and clay tiles (terra cotta). Under fire exposure, many masonry walls will remain intact. However, due to thermal expansion caused by severe heating of the exposed surface (usually the interior surface), ordinary brick, block and stone walls may sometimes lean out at the top and collapse. The integrity of masonry walls depends to a large extent on the quality of the mortar bond at the joints. Collapse also may occur for other reasons, including failure of a non-masonry supporting element, thermal expansion of floors, beams or trusses, or impact loading due to collapse of a floor, a roof, another building, or an explosion. A brick veneer wall depends for its integrity on the wooden structural wall to which it is fastened. If the wooden wall is damaged, the brick wall may collapse.

Concrete. Concrete is typically composed of portland cement, sand and coarse aggregate, for example, gravel, stone, cinders, slag, shale, vermiculite. The proportions may vary, for example, from 1:1:3 for columns to 1:3:6 for foundations. Concrete has high compressive strength but low tensile or shear strength. When exposed to elevated temperature under load, the compressive strength decreases and is one-half of its normal value at a temperatures of about 1100°F (593°C). When exposed to rapidly rising temperatures, concrete is susceptible to spalling which is the (sometimes violent) loss of surface material. Spalling is attributed to the rapid generation of steam and depends upon moisture content (generally above 5%) in the concrete, type of aggregate and compressive load. Spalling is more likely in concrete which has not had sufficient time to lose its initial water of hydration, a process which continues for years in heavy concrete sections.

Ordinary concrete contains no steel reinforcement (or only light reinforcement). Concrete blocks may be made from cement sand and gravel, or from cement and sand alone, or from cement, sand and cinders.

Reinforced concrete is a composite mixture in which steel rods or bars are used to provide tensile and flexural strength. Fire may cause the concrete to spall away from the reinforcing steel. The strength of the concrete structural element depends upon the close bond between the steel and the concrete. Damaged concrete may be structurally unsafe. The tendons used in prestressed concrete totally lose their prestress at 800°F (427°C).

Steel. Steel has high tensile and compressive strength and is used in buildings in many sizes, shapes and products. Steel loses strength at elevated temperatures. When used as a structural member its yield, tensile and compressive strengths decrease to one-half of its normal value at a temperature of about 1000 to 1100°F (538° to 593°C). The color of heated iron and steel is sometimes used as a measure of temperature (see table 3.2.3-1). Steel is used in rolled or built-up members, in bar and thin sheet "C" joists, as channels, tees and angles, and as a variety of connectors such as nails, screws, bolts, hangars, and gusset plates. The fire characteristics of the steel, including high heat conductivity, substantial thermal expansion and decrease in yield strength at high temperatures, may be critical factors in a fire. For instance, a 20 ft steel member will elongate almost 2 in when heated to 1000°F (538°C). If restrained, it will buckle to accommodate the expansion. The buckling may cause structural collapse and may be well removed from the point of origin of the fire.

Gypsum. Gypsum is used both for plaster and for manufactured wall boards. Gypsum is one of the few materials which absorbs heat from a fire, rather than contributing to the fire. It performs well in fires. It is widely used in fire-resistive assemblies. If the question of fire resistance is an issue, careful examination of the rear of several full sections should be made to determine if the board has a label or marking indicating it was listed by UL (Underwriters Laboratories Inc.) or FM (Factory Mutual Research Corp.). If the board is listed, then the installation should be compared with the code requirements, particularly in type and spacing of nails, cement cover over the nails, taping of all joints and firestopping of the structure.

Wood. Lumber is sawn wood used for construction purposes, although the word timber is often applied to large cross sectional pieces of lumber. Under fire exposure, wood undergoes a dehydration, followed normally by a burning and/or charring process. Charred wood has readily defined layers or zones. The charring rate is roughly 0.025 or 1/40 in/min, but varies significantly with species, density and moisture content. The relatively thin wood members of frame construction may lose structural strength rapidly on fire exposure. Thick structural members may retain their strength for long periods but the structure itself may fail because of failure of the connections.

Table 3.2.3-1 Approximate Color of Glowing Hot, Solid Objects

Appearance	Temperature °F	Temperature °C
No emission detectable	Less than 885	Less than 475
Dark red	885-1200	475-650
Dark red to cherry red	1200-1380	650-750
Cherry red to bright cherry red	1380-1500	750-815
Bright cherry red to orange	1500-1650	815-900
Orange to yellow	1650-2000	900-1090
Yellow to light yellow	2000-2400	1090-1315
Light yellow to white	2400-2800	1315-1540
Brighter white	higher than 2800	higher than 1540

Source: Woodburners Encyclopedia by J. Shelton and A. B. Shapiro. Waitsfield, VT, Vermont Crossroads Press, Inc., 1976, p. 13.

Wood cannot be "fire proofed" or made "noncombustible". However, it can be treated to reduce its rate of burning by a variety of surface treatments and impregnations with mineral salts. Pressure impregnation is one of the most effective methods of reducing surface flame spread, rate of heat release and smoke generation. If there is an apparent poor performance of impregnated or surface-treated wood, samples should be removed and tested for adequacy of the treatment.

Plastics. This term refers to a group of organic substances (resins) of high molecular weight which can be shaped or molded into finished solid products. Cellulosic plastics, which include cellulose acetate, ethyl cellulose, methyl cellulose and cellulose nitrate, are produced by chemical modification of cellulose. Some plastic products are blends, combinations or composites with unique properties; some can be compounded to be thermoplastic or thermosetting. Thermosetting plastics are those which undergo chemical reaction and cure during molding and do not melt. Some thermoplastics melt at temperatures only slightly above 212°F (100°C) and may form liquid pools and burn intensely in a manner similar to flammable liquids. Examples of the two types of plastics and quoted values of service temperatures and ignition temperatures are given in table 3.2.3-2. These temperatures may not relate directly to actual performance of products in fires, since the test methods do not take into account specimen size, heat transfer properties, aging, etc.

The fire performance of plastics depends upon type, use and level of exposure. Some plastics form a char structure which may inhibit further burning, but most plastics will burn rapidly and generate heat, smoke and potentially toxic gases at fire temperatures. The plastics may be almost completely consumed, and the investigator should investigate for the presence of plastics in fires which reached high intensity early.

Table 3.2.3-2 Plastics

	Typical Uses	Continuous Service Temp[1] °F	Ignition Temp[2] °F Flash	Self	Decomposition Temp Range[3] °F
<u>Thermoplastics</u>					
ABS	Piping, refrigerators, telephones	175-212	-	-	-
Acrylic/Methyl Methacrylate	Glazing, light diffusers, furnishings	170-230	540-570	830-860	340-570
Cellulose Nitrate	Throwaway test tubes	120-160	285	285	-
Polyamide (Nylon)	Carpeting, clothing, appliances	180-250	790	795	590-715
Polycarbonate	Glazing, appliances, light diffusers	250	-	930	-
Polyethylene	Containers, vapor barriers	160-230	645	660	635-840
Polypropylene	Wire insulation, appliances, piping	190-280	650	730	625-770
Polystyrene	Appliances, furnishings, thermal insulation (foam)	140-175	650-680	910-925	570-750
Polytetrafluorethylene (Teflon)	Cooking utensils, wire insulation	500	-	985	950-1000
Polyurethane	Furniture cushioning, coatings, thermal insulation (foam)	250-300	590	780	-
Polyvinyl chloride	Floor and wall coverings, wire insulation, piping, upholstery, clothing, coatings	150-175	735	850	390-570
<u>Thermosetting</u>					
Alkyd	Paints, lacquers				
Epoxy	Protective coatings, reinforced plastics	350	-	-	
Melamine	Tableware, laminates	210	885-930	1150-1190	
Phenolic	Laminates, appliances	280	900	-	
Polyester	Partitions (glass-reinforced), boats	250-350	655-750	810-910	
Silicone	Electrical insulation, coatings, grease	350-525	-	-	
Urea formaldehyde	Thermal insulation	120	-	-	

[1] Plastics Properties Chart, Modern Plastics Encyclopedia and other sources.

[2] ASTM D1929; various sources.

[3] Flammability Handbook for Plastics by C. J. Hilado. Westport, CT, Technomics Publishing Co., 1974.

Note: NFPA Fire Protection Handbook, 14th Ed., Table 3-7A provides a listing of Trade Names of Plastics with their composition.

Flame retardants added in manufacture may be used to reduce the ease of ignition and flammability of some plastics.

<u>Insulation.</u> The principal types of thermal insulation used in buildings are (1) mineral wool batts, blankets and fibrous loose fill, (2) foamed plastics, (3) inorganic (vermiculite, perlite) loose fill, (4) organic (wood or cane fiber) boards and (e) organic (macerated paper) loose fill.

Batts and blankets may be supplied with an integral vapor barrier (asphalt-treated or aluminum-foil-faced Kraft paper) which is intended for application to the warm-in-winter surface of the wall or ceiling interior finish board. The paper facing is flammable and should never be left exposed. The batts are held together with a combustible binder. Plastic foam, which is combustible, should never be left exposed and most building codes require that a layer of 1/2 in (1.3 cm) gypsum board or equivalent barrier protection be provided.

Loose fill cellulosic insulation is commonly made of ground-up paper with chemicals added to reduce flammability. The more common chemicals used are boric acid, borax, and various sulfates and phosphates and these are added in amounts ranging generally from 15 to 30% by weight. If the chemicals are not added properly, they may segregate and leave portions of untreated paper. Loose fill insulation may be poured or blown into attics or blown into walls. Unless care is taken to maintain clearances around light and heat fixtures, and around flues and other heated surfaces and heat-producing appliances, smoldering of the cellulosic insulation may occur.

3.3 UTILITY SYSTEMS

3.3.1 Introduction

Brief descriptions of the types of utility systems found in buildings are provided. Those features and materials of the various systems which have resulted in fires and fire spread are discussed. The principal utility systems are:

1) Plumbing systems;

2) heating, ventilation, and air conditioning systems;

3) electrical systems.

3.3.2 Plumbing Systems

Plumbing systems include water supply and waste removal (sewage). Water supply systems, as the wording indicates, supply water to the building's fixtures and equipment. Sewage systems remove the waste products, usually accompanied by water for ease in movement, from the building.

Piping for both water supply and waste removal systems may be either metallic (copper, steel, or cast iron) or nonmetallic (plastics such as chlorinated polyvinyl chloride, polyvinyl chloride and acrylonitrile-butadiene-styrene, or CPVC, PVC, and ABS, respectively).

In some code jurisdictions, gas piping is included under the local plumbing code provisions and, as such, is a plumbing system. Piping for gas supply systems includes wrought iron (black pipe) and zinc-coated pipe (galvanized).

The major concerns with plumbing systems from a fire standpoint are with:

1) Piping, if metallic, providing an accidental ground for stray electrical currents;

2) piping, if nonmetallic, providing a fuel for nearby fires with the resultant spread of the fire;

3) penetration of fire-resistive walls and floors without proper protection (firestopping) leading to the spread of the fire;

4) leaks or ruptures in fuel gas piping and the possibility of ignition of the leaking gas.

Gas leaks have contributed to many accidental fires. The leak does not have to be within the building to pose a fire problem. Gas from leaks in the underground piping outside of a building has been known to follow the piping through the wall of the building and contact an ignition source within the structure. Also, gas leaking outside of the building has been known to have entered the sewage system and flowed back into the building through untrapped floor drains, reach an ignition source within the building and explode. Natural gas and liquefied petroleum gas have no natural odor. They are odorized artificially. The odorant may be removed as gas leaks through the earth or it may be absorbed in the scale in the inside of the pipeline. As a consequence, the absence of any reported gas odor does not necessarily mean that gas was not present. Gas leaks in the underground gas utility systems which result in accidents should be reported to the National Transportation Safety Board. While the Board must investigate any accident in which a fatality occurs, the Board also will assist in the investigation of any serious gas utility accident.

The major concerns from fire in plumbing systems are with: (1) leakage from joints, especially in gas piping or sewer systems where sewer wastes may produce methane; and (2) improperly constructed penetrations of fire-rated assemblies by the piping or appurtenances. Under fire exposure certain installations of plastic piping, either water or waste, may contribute to spread of fire or emit toxic gases.

3.3.3 Heating, Ventilation and Air Conditioning

Heating. The basic types of heating systems are hot water, steam, hot air and electricity. Hot water and steam systems utilize water usually heated by coal, gas, or oil-fired boilers. The hot water or steam is conveyed to radiators and/or convectors by piping. In hot-air systems, the air is heated by coal, oil, or gas-fired burners, or electric-resistance heaters, and conveyed throughout the building through ducts. Electrical heating systems generally utilize either radiant panels (resistance heating cables) built into the floor or ceiling or baseboard heating coils (convective panels) with electrical service supplied directly to the heating units.

Ventilation. Mechanical ventilation is provided either in conjunction with the air conditioning systems, or is in the form of ventilating fans installed in exterior walls or roofs and exhausting directly to the outdoors or into exhaust shafts which lead to the outdoors. Supply or makeup air is usually obtained through grills in doors or exterior walls, or by air leakage through openings.

Air Conditioning. There are two primary types of air conditioning: (1) central systems with distribution ducts or piping, utilizing compression or absorption-type refrigeration equipment, or (2) packaged room or zonal air conditioners with free air discharge.

Central air conditioning systems utilize either electricity, natural gas, or fuel oil to operate the compressors and a refrigerant as coolant in the coils and condensers. Either cooled air is circulated through ducts or chilled water is circulated through piping to individual room or zone convectors.

Individual packaged room or zonal units are generally electrically operated with closed refrigerant circuits self-contained within the units and may, depending on the conditions of usage, take fresh air from the outside or recirculate the inside air.

Heating, ventilation and air conditioning systems may be the cause of the original fire or the systems may contribute to the growth and spread of the fire. Fire initiation may include:

1) Explosive ignition due to the accumulation of gas or oil vapors within the equipment from failure of equipment controls;

2) ignition of fuel gases or oils from leaks in the piping or in the equipment;

3) ignition of combustibles near flue pipes, combustion chambers, and radiant heating units.

In air duct systems, most codes require fire dampers at points where ducts pierce fire-resistive walls and floors (where not in a shaft). In fire investigations, it is sometimes important to determine whether

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these dampers operated properly. As noted below, air conditioning and ventilation systems are sometimes designed to perform specific functions, such as smoke removal from the area of the fire. It is sometimes necessary for the fire investigator to determine whether such a system was installed and whether the system operated as intended.

3.3.4 Smoke Movement

The explanation of heated smoke and gases rising and mushrooming under the roof, if not vented, is adequate for simple structures. In tall buildings a number of factors may cause the movement of smoke to locations far beyond the area of origin, without necessarily affecting the areas in between.

Smoke movement may be caused by:

1) Thermal energy of the fire;

2) wind;

3) stack effect;

4) air handling system;

5) special built in smoke removal equipment;

6) openings in the building;

7) atmospheric conditions.

The subject is extremely complex and space here permits only a brief treatment.

Thermal Energy. It is discussed in chapter 5.4.

Wind. The wind exerts a pressure on one side and a suction on the opposite side of the building. It may be powerful enough to overcome any of the other forces discussed here. It may change direction a number of times during the fire. It may blow in different directions at different levels of a high-rise building, particularly in congested areas where "canyon effects" may occur. The effect of the wind is increased when openings occur in the building. It is important to note that the wind at the fire may not have conformed to the information recorded at the nearest official weather station.

Stack Effect. This is due to differences between the inside and outside temperatures. The greater the difference, the greater the stack effect. Under cold weather conditions, normal air flow in the lower part of the building is from floors into shafts. The flow will decrease on successively higher floors until there is a "neutral zone", one or more floors where the flow is minimal. In the absence of wind, this

generally will be from 1/3 to 1/2 the height of the building. Above the neutral zone the flow reverses, from the shafts onto the floors, with the pressure (and thus the flow) increasing with height. The greatest flow therefore is from the lowest floors into the shafts and out from the shafts onto the highest floors. Thus top floor occupants sometimes may be the first to report a lower floor fire. In air conditioned buildings on a hot summer day, the flow may be reversed, that is downward. It should be kept in mind that the stack effect exists due to temperature difference and height. The fire does not cause it, the fire gases simply are transported by it. As an example of stack effect on fire gases, a rubbish fire on the ninth floor of a high-rise building under construction ignited PVC (polyvinyl chloride) air conditioning connectors. The fumes greatly distressed workmen on the 35th floor. They started to walk down the stairs but the stairwell was so full of noxious fumes that they got out at the 25th floor. They smashed the glass windows to get relief. This movement of gases from a lower to an upper floor was due to stack effect.

Air Conditioning. The investigator should determine the effect of the system on the fire. If the system was supposed to react to the fire in some way, the suggestions in the next paragraph are pertinent.

Special Smoke Removal Equipment. In some buildings special equipment is provided to vent the fire area. It may be triggered automatically or manually. In other buildings the air conditioning system may have been designed to assist in controlling the spread of smoke.

There are two questions the investigator can ask:

> "Did the special smoke removal equipment operate as designed? If it did operate as designed, were the results adequate?"

Openings in the building. Openings in the building, particularly large ones, can disrupt stack effect, multiply the wind effect, and disrupt the operation of mechanical equipment. When and why openings occurred might be important information as the fire investigation develops.

Atmospheric Conditions. When the temperature of the atmosphere is constantly decreasing as height increases, the condition is called "lapse". Under "lapse" conditions smoke will move up and away from the fire. If there is a layer of air warmer than the air below, this layer is called the "inversion layer". It acts as a roof to rising smoke. A high rise building may penetrate an inversion layer. This causes substantial differences in the smoke situation above and below the layer.

3.3.5 Wood-Burning Stoves and Furnaces

In recent years, there has been a growth in the use of wood-burning stoves and furnaces to provide either primary or supplemental heating. Such equipment, if not installed with adequate clearances to nearby combustible materials are potential sources of accidental fires. The burning of wood leads to the production of creosote which tends to deposit in the flue pipes and chimneys. This is particularly true of the newer so-called air-tight stoves. Operation of these stoves at low-firing rates enhances the production of creosote. The buildup of creosote in the flue pipes and chimneys can lead to a severe fire in the flue and chimney as the creosote is combustible. Flues and chimneys, be they masonry or the newer all-fuel triple-wall metal variety, should be able to withstand a total burnout. However, they may not due to deficiencies which may have been built in or have occurred with the passage of time.

3.3.6 Electrical

Electrical service consists of the following:

1) Service drop wires, either overhead or underground (from the public utilities' lines to the building);

2) service-entrance wires (from outside of building to equipment on the inside);

3) meter;

4) service entrance switch (to disconnect entire installation from public utilities' lines);

5) panel boards providing fuse or circuit breaker protection as well as disconnect means for each of the individual branch circuits;

6) grounding system;

7) distribution system - individual circuits, for lighting, appliance, and equipment operation.

There are six different types of wiring systems in common use. They are: (1) rigid conduit; (2) thin wall conduit; (3) flexible conduit; (4) nonmetallic-sheathed cable; (5) armored cable; and (6) knob-and-tube (which is seldom used today). Electrical codes are very specific with regard to where each of these systems may be used.

Junction boxes and outlet boxes are required at every location where wiring is spliced or insulation is removed, and at fixture locations.

In older buildings, electrical installations may have been made without outlet boxes at all splices and where insulation had been removed. In these locations, and where the wiring has been run in joist or stud spaces, dust, cobwebs and other easily ignitable materials may be present. If the splices and joints have not been properly made, there is a possibility of either short circuits or overheating of wire junctions thus leading to fire.

Another common cause of electrical fires, particularly in single-family dwellings, is the replacement of fuses of one rating with those of higher rating, that is, replacement of 15 ampere fuses with 20 or 30 ampere fuses. This practice may result in the overloading of the electrical wiring causing overheating and breakdown of insulation, and, if in close proximity to combustibles, eventually to smoldering and possible flaming ignition.

Electrical distribution systems and electrical fires are discussed in greater detail in chapters 4.4 and 4.5.

4. Ignition Sources

4.1 FLAMING IGNITION

4.1.1 Introduction

Flaming ignition itself requires no explanation or definition as we are all familiar with it. The investigation is often quite straightforward when accidental flaming ignition occurs. Many fires ignited by open flames occur with people present and are either snuffed out quickly or witnesses can describe for the investigator the type of ignition, what was ignited, and how. Without witnesses, the ignition mode must be determined from available evidence.

4.1.2 Matches

The most common flaming ignition source is the match. Fires started with matches include: children playing with matches, careless disposal of flaming matches into trash cans or receptacles, and the use of matches by the arsonist, often combined with large quantities of combustible materials, flammable liquids, or other accelerants. Arsonists have used matches as delayed ignition devices by tucking a burning cigarette into a book of matches. Sometimes the remains of the match book can be found in the debris, including the wire staple used to fasten the matches into the cover, indicating to the investigator that the fire may have been set. The wire staple used in many book matches is smaller in size than the normally-used, office-type wire staple. The presence of the smaller staple in the fire debris, while not positive proof of a set fire, should, at least, start the investigator thinking of that possibility.

It is difficult to ignite thick materials with a match; as an example, attempting to ignite the wooden arm of an upholstered chair is almost impossible. Some intermediate material is necessary to ignite large items from a simple match. Crumpled newspapers are an excellent kindling, particularly when placed on an upholstered chair or sofa. Draperies or clothing also can serve as intermediate materials. An effective arsonist will attempt to utilize for his intermediate materials those materials normally present to avoid suspicion. The only clue the investigator may have in this situation is that the intermediate materials were not found in their normal location in the building.

4.1.3 Heating Equipment

Another flaming ignition source is heating equipment. This includes furnaces, boilers, stoves, space heaters, fireplaces, and their flues, chimneys and vents. Fires can originate from the escape of fuel, with subsequent ignition, ignition of nearby combustible surfaces from overheated equipment surfaces*, and escape of heat or flames from flues and chimneys. Faulty operation of heating equipment or its associated controls can produce run-away fires and explosions. Unusual ignitions can occur from heating equipment long after the original installation, such as ignition of wood in contact with steam pipes after several years of exposure.

The types of heating equipment and the possible sources of flaming ignitions are so varied that it is not possible to describe all of these adequately in this Handbook. The best that can be done is to call the investigator's attention to the large role heating equipment has in accidental fire starts. In other words, the possibility of a fire from the heating equipment, if it was operating at the time of the fire, must be given serious consideration.

In recent years, there has been a renewed interest in wood stoves for either supplemental or primary heating. These heating devices appear to be more hazardous than central heating systems. As a consequence, it is anticipated that the number of accidental fires from these stoves will be on the increase over the next several years until the consumer learns to control the hazards or the renewed interest diminishes. The point for fire investigators to remember is that if the fire scene contained an operating wood stove, be suspicious of it unless all of the available evidence points elsewhere. (See chapter 3.3.5 on wood stoves.)

4.1.4 Cooking Equipment

This category of flaming ignitions is responsible for the largest number of residential fires in the United States each year. However, few of these fires reach major proportions and, as a consequence, result in fire department response and subsequent investigations (1).[1]

Those that do result in fire department response are generally the result of ignition of oils, greases, and fats on the cooking range. Nearly all building codes permit the installation of combustible kitchen

*Moderate increases in the surface temperature of a heater can greatly increase radiant heat delivered to nearby surfaces (see chapter 5.4).

[1]Figures in parentheses refer to references at the end of the chapter.

cabinets over the cooking range. In the event of a fire on the range, there is a good possibility the cabinets will be ignited. From this point, it is only a short period of time until the complete kitchen is involved. The investigator normally has little difficulty with this fire cause as the physical evidence as to the source of the fire (pans on the burners and/or the controls in the "ON" position) is usually evident.

Other cooking equipment is sometimes responsible for fires usually due to thermostat failures in appliances such as toaster ovens, deep fat fryers and electric fry pans. Determining that one of these appliances was the cause is relatively easy, unless the fire damage is extensive. Even then a history of problems with the appliance may be uncovered in interviews with witnesses.

4.1.5 Electrical Equipment

Electrical equipment, which would include some of the appliances under "Cooking Equipment", is covered in chapter 4.4 and will not be discussed here.

4.1.6 Other Flaming Ignition Sources

Many open flame devices are used in the construction of buildings, such as salamanders for heating and torches (now, usually propane) for sweating pipe joints in copper plumbing. These, and other open flame sources, have been responsible for many fires in buildings under construction. The plumber's torch is a particularly frequent ignition source due to the nature of the operation. A typical story goes like this: The plumber is sweating a fitting in the common bathroom wall between two apartments on the first floor of a two-story apartment building. The wall is insulated (for noise reduction) with paper-wrapped, fiberglas batts. The plumber places a piece of sheet metal behind the fitting to keep the torch flame off of the batts. He is having difficulty seeing what he is doing as the electrical circuits have not been completed. The plumber is working away when all of a sudden he sees a flame emerge from behind the sheet metal and race up the paper into the wall of the floor above before he can stop it. The fire extends into the attic and burns off the roof and 16 apartments on the floor above before the local fire department can contain the fire.

Fires caused by cutting and welding operations also are fairly frequent. Three problems are inherent in these operations of which the investigator should be aware. First is the torch itself. Careless handling of the torch can cause ignition of nearby combustibles. Second is the sparks and hot slag resulting from the cutting or welding. These may fall onto nearby combustible materials, start smoldering fires of which the welder is unaware, and later, after everyone has left the premises, break out into flames. Third is the transmission of heat through the metals being worked on resulting in ignition of combustibles in contact with the reverse side of the metal. This latter problem is particularly frequent in shipboard repair work.

4.1.7 References

(1) Highlights of the National Household Fire Survey. National Fire Prevention and Control Admin., Dept. of Commerce (US) (no date).

4.2 SMOLDERING COMBUSTION

4.2.1 Introduction

In some fires, the first material to ignite exhibits a non-flaming, slowly propagating combustion. Similar behavior is often observed, after the flames have died, as glowing embers. Both are examples of smoldering combustion. This deep-seated combustion process consumes fuel very slowly, with the leading edge or front generally moving at rates about one inch per hour. As a result, it generates relatively little heat and small quantities of combustion gases compared to flaming combustion. The danger lies in the nature of these gases and in the difficulty in detecting smoldering before it changes to a flaming mode.

4.2.2 Ignition by Smoking Materials

For homes, one of the major reported sources of destructive fires is the glowing cigarette, often igniting trash accumulations, bedding or upholstered furniture (1).[1] Carpets, curtains, draperies and other items are less frequently involved.

Literally hundreds of billions of cigarettes are smoked each year in the United States. This means that every minute of the day hundreds of thousands are being lit, smoked, and discarded. Fortunately, the vast majority of these "smokes" are successfully extinguished. The time required for an unpuffed 3.3 inch (8.4 cm) cigarette to burn its full length (in air) in a horizontal position is approximately 20 min. However, if the cigarette were to burn on a piece of interior furnishing (such as a mattress, chair, or sofa) covered by a piece of clothing, newspaper, etc., it may smolder for 45-60 min before burning its full length. Typical tip temperatures may reach 1100°F (593°C).

The fuel must be porous to be ignited by a smoldering cigarette. Once ignited, the heat decomposes more material to form a porous char and volatile gases. Air slowly diffuses through the pore structure to the hot smoldering front. There the char reacts with the air to give some carbon dioxide, carbon monoxide, and enough heat to continue the combustion. The char structure is critical to smoldering in other ways too. It is an effective insulator, so that the small amount of generated

[1]Figures in parentheses refer to references at the end of the chapter.

heat is not dispersed. It also maintains the open maze through which air continues to diffuse to the smoldering front. Should the char collapse, melt, or produce tarry material which blocks the pores, the smoldering would cease. For these reasons, most common plastics do not smolder.

However, most upholstered furniture (chairs, sofas, etc.) and mattresses are made with cover fabrics and porous stuffing materials whose ignition temperatures (500-700°F, 260-371°C) may be easily exceeded by burning cigarettes. Some upholstery cover fabrics resist cigarette ignition better than others. Wool, nylon, olefin, polyester, and various other synthetic plastics generally melt rather than smolder. Cotton, rayon, linen, and blends of these fibers (cellulosic fabrics) will ignite from burning cigarettes and smolder. Leather will smolder and silks will not.

Filling materials used in upholstered furniture and mattresses consist of cotton batting, urethane foam, foam rubber and polyester or combinations of these. Of these, cotton batting and foam rubber can easily be ignited by burning cigarettes. Urethane foam, and polyester will melt under the heat of a cigarette and usually will not ignite. However, under certain circumstances, urethane foam covered by upholstery fabric can be ignited (smolder) and even burst into flames. Such an occurrence might take place in a crevice of a chair or sofa where a foam cushion abuts a vertical side arm. A smoldering cigarette in this location may easily start a fire.

Whether a cover fabric is cellulosic or synthetic (plastic) may be determined by applying a match to a sample of the fabric and observing whether it melts, chars or flames. If on extinguishing the flame a glowing persists, then the fabric is cellulosic (cotton, rayon, linen, or blends). If the fabric melts and drips, it is synthetic, for example: polyester, olefin, or nylon. Wool will not sustain combustion from a low heat source and will give off a pungent odor similar to the smell of burning human hair.

In filling materials, cotton batting is easily identified as is polyester fiberfill. Determining whether a foam material is rubber or urethane can be accomplished by a simple match test, that is, by ignition of a small piece, extinguishing and smelling the odor of residual smoke. The two classes of materials give off distinctive and different odors, and the identity of the sample at hand can be obtained by comparison with known foams. If these are not available, foam rubber will smell of burning rubber and polyurethane foam will have a "sweet" odor.

4.2.3 Hazards of Smoldering

Three hazards are associated with smoldering combustion. The first lies in combustion products. The smoke is produced slowly. Even at this slow rate, dangerous gases are being generated. The slowly diffusing oxygen sees vast active fuel surfaces. This excess of carbon promotes the formation of noxious carbon monoxide over the less dangerous carbon dioxide. During the long alarm delay, the toxic gases accumulate and may be responsible for incapacitation and deaths, even before there is major damage to the premises.

The second danger lies in the eventual transition to flaming combustion. Char temperatures in cotton, for example, can exceed 900°F (482°C), well above the fire point of the volatile gases being "boiled off" ahead of the smoldering front. Higher surface temperatures and the accompanying higher volatilization rate can result from even small increases in the air movement across the smoldering area. This brings oxygen (air) to the smoldering fuel at a higher rate. This, in turn, increases the char burning, raising its temperature, which in turn, pre-heats more fuel faster, producing more gases and char at an ever-increasing rate. Should the concentration of these gases exceed their lean flammability limit, a sudden eruption of flames would result.

The third danger arises when uninformed persons try to extinguish smoldering fuel. Often the fire appears to be extinguished, the material is not removed to a safe location, and a serious fire breaks out later. Deep-seated combustion is very well named.

4.2.4 Analysis of the Fire Scene

What can one look for to determine whether a smoldering ignition began a fire? Unfortunately, if the fire flames, the post-fire scene will be the same as after an initially flaming fire. The accounts of witnesses to the fire may be helpful, particularly if they remember smelling smoke for some time before the fire was discovered.

If the fire goes out or is suppressed before flaming begins, the evidence will be more obvious. Look for a partially charred mattress or chair. Since relatively little soot is generated, note the cleanliness of the walls. The soot deposition or wall charring should be slight and localized near the source. (If flaming occurs, soot deposition will be extensive.) Smoldering will rarely ignite flammable fluids or solids which are not in direct contact; thus their continued presence is an indicator. Lastly, because the smoldering propagation is so slow, the ignition source, such as a cigarette or electrical fixture, should be obvious to the careful investigator.

4.2.5 References

(1) Derry, L., Fatal Fires in America: How They Happen, Where They Happen, How to Stop Them. Fire Journal, Vol. 73, No. 5, pp. 67-79, September 1979.

4.3 SPONTANEOUS IGNITIONS

4.3.1 Introduction

Spontaneous ignition, formerly called spontaneous combustion, has been widely used to classify the apparent ignition and burning of material without the external application of heat, spark or flame usually considered necessary for ignition. In most cases the term spontaneous is misleading. Many prefer the term "self-heating" or "self-ignition" and these terms often will be found in the literature. These terms also may be somewhat misleading since heating and ignition, if they occur, are usually dependent on both special storage conditions and the introduction or presence of chemical or biological material, which is necessary if the process is to occur.

Spontaneous ignitions are spontaneous only in the sense that flames suddenly appear on the surface of a previously nonflaming material. The conditions leading to this flaming are usually lengthy ones involving the build up of heat within the material over periods of hours, days, months or even years in some instances.

There are some exceptions to this statement. Some very reactive or pyrophoric materials may produce flames almost immediately when exposed to oxygen or another chemical with which a rapid reaction can occur. Such ignitions occur on the surface of the reacting material and thus can occur in periods of a few seconds or less. These materials normally require special handling in the industrial plant or laboratory.

Ignition leading to flaming requires the generation of heat at a rate faster than it can be lost to the surroundings. This is an especially important requirement if a material is to self-heat to a state where ignition is possible. Thus, almost all cases of spontaneous ignition require that the material involved be in bulk form which, in itself, comprises a thermal insulator. The outer portions of the material thus form an insulating layer and serve to prevent rapid heat loss from the central core. Of course, the size of the material bulk which can self-ignite will be a function of its coefficient of thermal conductivity, its thermal reactivity, the temperature of the surroundings, and the degree of convective cooling around material.

Self-heating may occur in materials for a number of reasons: (1) the material may be unusually reactive at normal temperatures, (2) normally inert materials may become activated through additives either during bulk storage or prior to it, (3) biological action may raise the temperature to a level at which the material itself can start reacting, and (4) stowage of hot material can result in self-heating to ignition even though the same material stacked in the cold condition shows no evidence of self-heating.

The exact nature of self-heating has not been clearly defined. As suggested above, it may vary with the type of material and/or the stimuli required to initiate the heating process. In almost all instances, the process is possible because of the nature of thermochemical reactions. If a pile of material starts reacting at normal temperatures, the insulating effect of its outer layer limits heat loss to the surrounding air. Temperatures build up in the center of the pile with the outer portions acting as a thermal insulator. Thus, spontaneous ignition starts by heating up and usually charring the interior of a pile of material prior to any discoloration of the outer surface.

Self-heating materials have been known, in the early stages of the process, to release odors, smoke and perhaps have slightly elevated surface temperatures. If the pile of self-heating material is opened or split down the center, the center of the pile will be found to be hot, discolored, or charred, depending on the length of time the process has been in progress. If, after opening the pile, it is both hot and charred, there is great danger that rapid ignition will occur, quickly involving the bulk of the material. Because of this, it is much safer, if the pile is large, to probe the pile with a thermometer or thermocouple to determine whether self-heating is in progress. On the assumption that the material storage temperature conditions have been reasonably constant for a considerable prior period, the absence of temperatures within the pile significantly above the previous storage temperature indicates no self-heating.

4.3.2 Occurrence

4.3.2.1 Biological Initiation

Perhaps the most common occurrence of spontaneous ignition used to be that of hay which had been incompletely dried prior to bulk storage in barns (1,2,3).[1] The moisture present allows biological action to take place. The heat release from this action can raise the temperature within a bulky and well-insulated pile of hay to a temperature of 167-176°F (75-80°C). At this point biological action is destroyed by the heat. This temperature, however, is high enough to permit, under some

[1] Figures in parentheses refer to references at the end of the chapter.

storage conditions, continued heating of the pile resulting eventually in a fire. Such fires were reasonably common when hay was stored in bulk form. With the introduction of baling equipment, resulting in storage of hay at much higher density, spontaneous ignition has been less frequent. Since spontaneous ignition of hay is well known, this cause is often assigned. It is important that the unburned pile not be disturbed until the investigator can examine it. If there is no evidence of heating within the pile, spontaneous ignition is not the cause.

4.3.2.2 Chemically-Reactive Materials

Another common cause of spontaneous ignition is the oily rag (1,2,3). Unsaturated vegetable oils absorbed on cotton waste or rags can readily self-heat and ignite. A list of these oils in approximate order of sensitivity from high to low reactivity is as follows:

1) Linseed;
2) tung;
3) hemp;
4) poppy seed;
5) sunflower seed;
6) tobacco seed;
7) soybean;
8) corn;
9) cotton seed;
10) rape seed;
11) castor.

These materials combine with oxygen from the air, releasing heat in the process. Their adsorption on cotton or other fiber can greatly increase the surface-to-volume ratio through which this oxidation can occur and, thus, increase heat release per unit volume. If the oil soaked rags or fabrics are wadded up in a large ball, the heat liberated will be conserved and ignition may occur. If, on the other hand, the rags had been suspended from a line in one or two layer thickness, rapid heat loss to the air would prevent ignition. Cargo nets and empty sandbags, treated with oil for preservation, also have been known to ignite spontaneously when stored in piles.

Some of the oils previously mentioned were commonly used in paint and varnish manufacture and numerous fires have been blamed on improper storage of oil-soaked rags. This type of accidental ignition has been greatly reduced by the introduction of latex paints, commonly used today.

Note that all of the above oils are vegetable. Petroleum oils, as found in garages, do not ignite spontaneously. This difference in behavior between vegetable and petroleum oils is not well recognized. Sometimes fires are attributed to mineral-oil-soaked rags by persons who may be attempting to misdirect the investigation.

Both wood and coal appear to be sufficiently reactive to self-heat and ignite under conditions which conserve the generated heat (1-4). In most cases, though, these conditions involve very large piles, a more or less open structure such that air can penetrate the pile and an extended period of time. It is not likely an investigator will frequently encounter fires in which self-heating of coal is a possible cause. As a consequence, the self-heating of coal will not be discussed. However, if the need should arise, a good source of information on this subject is reference (6).

4.3.2.3 Initial Heating of Material

Materials safe at room temperatures can present spontaneous ignition hazards if stored in piles while at elevated temperature (4). For instance, both cellulosic fiberboard and glass fiber insulation material have been shown to self-heat when stored in large piles direct from the production process. This problem has been recognized and standards now require the cooling of the material below a temperature of 140°F (60°C) before bulk shipment of the cellulosic fiberboard (5). When spontaneous ignition is suspected, it is necessary to consider the circumstances along with available physical evidence. An accidental fire in a clothes dryer load may be thought impossible since the heat level of normal clothes drying is too low to produce ignition of cloth. Examination of the evidence, however, might reveal the presence of foam rubber garment pads. Foam rubber is a material, which, when heated to moderate temperatures, can ignite spontaneously.

Like foam rubber, polyurethane foam can become self heating after being heated to moderate temperatures. Polyurethane foam "buns", freshly manufactured, are isolated for a period of time to cool or to permit safe ignition, if ignition should occur.

4.3.2.4 Pyrophoric Metals

Some metals are pyrophoric in that these metals can ignite spontaneously in air under certain circumstances. These metals include plutonium, uranium, thorium, zirconium, hafnium, magnesium, calcium, potassium, and sodium. The conditions which will produce ignition vary widely from metal to metal. Liquid sodium will react violently when dropped into water. Uranium scrap will ignite spontaneously, particularly under summer heat conditions, if not stored under oil or water. The subject of spontaneous ignition of metals is a complex one. If spontaneous ignition of metals is suspected as a possible cause of a fire, the investigator should seek the best technical advice available. Reference (7) gives a good description of pyrophoric metals.

4.3.3 Material Tests for Spontaneous Ignition

If the fire investigator needs to determine whether a material may have undergone spontaneous ignition, there are several test methods which can be used to measure some aspects of self-heating behavior. However, as the services of a laboratory will be needed to conduct these tests, the investigator will need to seek assistance from qualified laboratories.

4.3.4 Summary

Numerous unwanted fires have undoubtedly occurred as a result of spontaneous ignition. Attempts to assign this as a cause are not often successful. The evidence is often destroyed before the fire is discovered. The fire investigator should remember that spontaneous ignition, in the sense discussed here, is always a process of heating from within. Unless this can be shown, assignment of spontaneous ignition as a cause of the fire is dubious.

4.3.5 References

(1) Fire Protection Handbook, 14th and earlier editions. Boston, National Fire Protection Assoc.

(2) Kirk, P. L., Fire Investigation. New York, John Wiley & Sons, Inc., 1969.

(3) NFPA Inspection Manual. 4th edition. Boston, National Fire Protection Assoc., 1976.

(4) Mitchell, N. D., New Light on Self-Ignition. NFPA Quarterly, Vol. 45, No. 2, pp. 165-172, October 1951.

(5) Federal Specification, Insulation Board, Thermal and Insulation Block, Thermal Federal Specification LLL-1-535, November 1960.

(6) Handbook of Industrial Loss Prevention, 2nd edition. New York, McGraw-Hill Book Company, 1967, p. 73-2.

(7) Smith, Richard B., Pyrophoricity, A Technical Mystery Under Vigorous Attack. National Fire Protection Assoc. Quarterly, Vol. 51, No. 2, pp. 137-142, October 1957.

4.4 ELECTRICITY AS AN IGNITION SOURCE

4.4.1 Introduction

Because all practical conductors of electricity exhibit some resistance to the flow of electrical current, the production of heat within an electrical system is an inescapable result. An electrical system should be designed and built so that the heat generated will be minimized and dissipated safely. If the heat developed within the system is allowed to build up to the point where it causes damage to some portion of the electrical system, that damage may result in failure of the system and ignition of the system itself and/or the building or its contents. The investigator must be familiar with wiring and, at the very least, be able to present (and defend) an accurate and authoritative report that a specific fire was electrical in origin. On the other hand, the investigator may have to be able to prove that the fire was not electrical in origin in order to prevent the loss of an arson case due to the inability to rule out a frequent accidental cause of fires.

Electrical fires can be divided into two major classifications. They are:

1) Fires originating within the electrical distribution system. The electrical distribution system consists of all of the permanently-installed electrical equipment from the point where the power company's wires first terminate in or on the building (usually at an electric meter) up to and including receptacles, switches, and junction (splice) boxes to which "Utilization Equipment" is connected. "Utilization Equipment" is defined in the National Electrical Code (NEC) (1)[1] as: "Equipment which utilizes electrical energy for mechanical, chemical, heating, lighting, or similar purposes".

2) Fires originating within the electric utilization equipment. Electrical utilization equipment includes appliance and fixtures attached to the electrical distribution system. Such equipment may be permanently connected (hard-wired) or cord-connected with a plug to a receptacle.

There are fires involving electrical appliances (Utilization Equipment) which should not be considered electrical in origin. For example: a child placing paper in a toaster, or clothing too close to an electrical heater.

[1] Figures in parentheses refer to the references at the end of the chapter.

4.4.2 National Electrical Code Definition

Some electrically-caused fires are relatively easy for the trained investigator to recognize and describe. Others can be quite complex and require specialized technical assistance. To understand how or why a particular type of electrical fault (and resulting fire) can occur, a knowledge of the terms, "voltage" (E), "current" (I), "resistance" (R), and "power" (P) and their interrelationships (such as $E = IR$, $P = EI = I^2R = E^2/R$) is necessary. This information is available in textbooks on the subject and will not be covered here.

Fire investigators also should have an understanding of the basic provisions of the National Electrical Code (NEC), as well as its terminology for electrical conductors and equipment used in electrical distribution systems. Some of this information is presented below for the common forms of residential electrical distribution systems.

Modern residential electrical distribution systems make use of three or more wires to provide power to electrical utilization equipment. These wires are the "grounding" conductor; the "grounded", "identified", or "neutral" conductor; and one or more hot or unidentified conductors. The terms "grounding", "grounded", "identified", and "neutral" are defined in the NEC since these terms describe wires used in very specific ways in the system; all other conductors are simply described by common names such as, "hot", "lineside", and so on. The NEC also requires that those conductors given a defined name in the Code be marked but these same conductors cannot have a color which could cause them to be mistaken for the "grounding" and "grounded" conductors. To summarize these Code rules:

"Grounding" Conductor - This is a safety wire which is intended to carry the current which might escape due to a failure in the insulation of the hot wire (or failure of the insulation within an appliance) back to the source of the current. This wire is required to have green-colored markings (if it happens to be insulated) or it can be left bare (no insulation).

Some electrical wires are encased in a metal jacket (type AC armored cable, also known as BX cable) or are installed in metal conduit or tubing (rigid conduit or electrical metallic tubing, type EMT). The metal armor, conduit, or tubing can serve the same purpose as the "grounding" conductors and, under these conditions, the bare or green-colored conductor can be eliminated.

The "grounding" conductor (or metal jacket, armor, conduit or tubing) does not carry any current in a properly functioning electrical system. The "grounding" conductor carries current only if there is a breakdown of the insulation of the other conductors, or a failure within the utilization equipment which would accidentally energize metal parts of the system, the utilization

equipment, or the building. The "grounding" conductor is intended to eliminate such a potential shock hazard by giving the current an alternate path to return to its supply. Since the "grounding" conductor is intended to be a low resistance path for the current to follow, and since a fault within the system or equipment to ground usually presents a lower resistance path than that through a properly operating appliance, the overcurrent protective device serving the hot conductor in the circuit should open, shutting off the faulted circuit when the current flows in the "grounding" conductor.

"Grounded", "Identified", or "Neutral" Conductor - This is a wire which is intentionally connected to the "grounding" wires at one, and only one, point in the electrical distribution system--the point at which the electric cables first enter the building (inside the "service entrance equipment"). It can be thought of as the wire which usually returns the current to the supply by completing the circuit after the current has passed through the appliance from the hot wire. It should be noted that there are some types of electric utilization equipment which may not need and will not use a "neutral" conductor since the equipment is connected hot-to-hot (line-to-line). Such equipment is usually quite large and consumes a great deal of electrical power, for example, central electric heating systems, central air conditioning systems, and so on. The more common situation is one in which some portion of the equipment is connected line-to-line while the remainder is connected line-to-neutral. Electric cooking ranges and electric dryers are examples.

The "grounded", "identified", or "neutral" conductor must always be identified by a white or natural gray color.

Hot Conductor (any wire not a "grounding" or "grounded/identified/neutral" wire - This is the wire which can be thought of as supplying the current to the appliance. A hot conductor must always be provided with "overcurrent protection" (a fuse or circuit breaker) where it receives its supply of electricity. Except in very special cases, not likely to be found in residential construction, a "grounding" or "grounded/identified/neutral" wire must never be connected through a fuse or circuit breaker. A hot conductor must always be insulated and may be any color other than green, white, or natural gray. In residential construction, the hot wire is usually black or red.

While the foregoing may seem a bit complex and confusing to the fire investigator just beginning the study of electrical systems, some time spent with publications written for electrician apprentice programs, or written for the home handyman, will aid in understanding the rules of proper electrical system design. For the present, remember that modern electrical distribution systems will have the following wires: a "grounding" conductor, a "grounded/identified/neutral" conductor and one or more hot conductors. There are three exceptions to this general rule:

1) Equipment connected hot-to-hot or line-to-line need not have a "neutral" brought to the equipment. This exception is rare in residential construction as electrical equipment will either be connected line-to-neutral or will have some portion connected line-to-neutral.

2) The "grounding" and the "grounded/identified/neutral" conductors may be one and the same for electric ranges, wall-mounted ovens, counter-mounted cooking units, and clothes dryers, but only for these appliances, and only where the supply wiring is direct from the service entrance equipment to the appliance.

3) When the equipment is supplied by an armored cable or by wires in conduit or tubing, the "grounding" conductor need not be used. In such cases, the metallic sheath of the armor, conduit, or tubing serves as the "grounding" conductor.

4) Older electrical distribution systems, such as those installed in residences 20 or more years ago, may not have "grounding" conductors. If supplied by armored cable or wire in conduit or tubing, the armor cable, conduit, or tubing may not have been designed to function as the "grounding" conductor and therefore the equipment may not be effectively grounded.

4.4.3 Short Circuits

A short circuit is an unintentional connection between a hot conductor and either a "grounding" or "grounded" conductor which results in current by-passing the utilization equipment (appliances, lighting, heating, and so on). If the hot (black or red) conductor contacts the "grounded/identified/neutral" conductor (white or natural gray), a line-to-neutral short circuit occurs. If the hot conductor contacts a "grounding" conductor (bare or green wire), the armor of a BX cable, a metal conduit, a metal water pipe or the frame of a washing machine, a line-to-ground short circuit occurs.

If there is little resistance at the point of the short circuit, the resulting current flow will be very large, probably far in excess of the setting of the Overcurrent Protection (fuses or breakers). Though fuses and circuit breakers open quickly under short circuit conditions, they cannot open instantaneously. As a consequence, there may be some momentary sparking due to the high current flow through poor and/or unintentional connection points in the system. Such sparking may be sufficient to ignite nearby combustibles. Sometimes the short circuit connection will be poor or the "grounding" path connections will be loose. Thus there may be enough resistance in the circuit to limit the

short circuit current to a value below the rating of the fuses or breakers, in which case they will not open. Or, the short circuit current may be just at the rating of the fuses or breakers, in which case they may take a relatively long time to open. In either case, the current flow within the system will be much higher than "normal". The fault will continue until either it clears itself or gets worse and causes an ignition.

If the overcurrent protection is set too high for the size of the wiring protected, it is even more likely that the wiring system could become hot enough to cause ignition before the fuse or breaker operates. Occasionally, fuses or circuit breakers fail to perform (are defective) or have been defeated (a penny under a fuse). Under such conditions, the short circuit current will continue until something else opens the circuit, such as the melting of one of the wires or operation of the "main" breaker or fuse, if one is installed.

A true short circuit is a rarity. In fact, it is both more accurate and more descriptive to speak of electrical faults as having some degree of impedance (resistance), as: a "high impedance fault", a "low impedance fault", and so on. (For fire investigation purposes, "impedance", a term often used by electricians and engineers, has the same meaning as the term "resistance".) Most electrical faults begin as high impedance breakdowns between hot side components or conductors and grounded components or conductors. High impedance simply means "high" in relation to a true short circuit, which can be thought of as a low impedance fault.

The resistance of a high impedance fault can be less than the resistance of the electrical load served by the circuit. This results in a fault current which is higher than the current created by the electrical load. The heat generated by the fault current, plus possible arcing and sparking at the point of the original breakdown, can cause the breakdown to progressively worsen until a low impedance fault develops or until the fuses or breakers operate.

A true short circuit is usually initiated by something outside of the electrical distribution system. For example, lightning-strike-induced breakdowns of electrical insulation, drilling or driving a fastener into an electrical cable, or dropping metal parts across adjacent bus-bars. If outside factors, such as those mentioned above, can be ruled out, then in almost all cases a short circuit will be the <u>result</u> of some deficiency in the electrical system and <u>not</u> the cause.

Short circuits should not be listed as a cause of a fire without additional details explaining the reason for the short circuit and why the overcurrent protection devices did not open the circuit under the short circuit conditions. This may be difficult to do, but to list a fire cause as due to a "short circuit" is similar to listing the cause as "unknown". In neither case, will there be a clear indication as to what caused the fire.

4.4.4 Electrical Distribution System as Ignition Sources

Based on present knowledge, there are at least six fundamentally different electrically-induced, ignition mechanisms. These are:

1) Overheating conductors;

2) on-line arcing/sparking;

3) glowing connections/glowing contacts;

4) exploding wires/exploding contacts;

5) overheating nonconductors ("high-resistance" shorts);

6) arc-faults.

Note that short circuit is not listed above for the reasons stated in chapter 4.4.3. Note, also, that the terminology used in the text is different than that generally used. Each of the six mechanisms is described and discussed. Tell-tale evidence or other information which may assist in determining the fire cause also is discussed.

4.4.4.1 Overheating Conductors

The usual cause of overheating conductors is for an electrical fault to occur (of the type described in chapter 4.4.3) or for an appliance to draw more current than the wires can deliver, accompanied by either the nonoperation or the malfunction of associated fuses or circuit breakers. Nonoperation of overcurrent protection is usually the result of resistance in the circuit which limits the current flow to some value below the rating of the fuses or breakers. An example would be the operation of a 1500 W portable electric heater on a lamp-cord-sized extension cord. In addition, nonoperation of the overcurrent protection could be due to their being rated too high for the wiring.

Malfunctioning of the overcurrent protection may be due to a defect within the fuse or breaker or they may have been disabled. Disabling can be by such means as a penny in an edison-base (screw-base) fuseholder, copper tubing in a cartridge fuse, or tampering with a circuit breaker mechanism. Malfunctioning of overcurrent protective devices under short circuit conditions results in large currents throughout the circuit, even in areas of the building not involved in the fire. As the wires are likely to be insulated with polyvinyl chloride (PVC), the fact that a malfunction has occurred will be evident as the PVC insulation will have softened and sagged away from the affected wires, all the way back

to the panel. By contrast, PVC insulation which is heated from the outside, will bubble, char and burn but will remain tightly bound to the wires.

With too much current (for example, 150 amperes in #12 copper wires; and in some situations less) the wire will heat, eventually melt, and cut off the power. In figure 4.4.4.1-1, note the rounded ends of the severed wire and the ball of copper near the end of one side of the melt. While this wire was internally heated, the same type of melt can be produced by external heating of the wire. However, except in severe fires, external heat is not sufficient to melt copper wires as the melting point of copper is around 1980°F (1082°C). Nevertheless, in the investigation, it will not always be clear whether the melting was the result of overcurrent and short-circuiting or the result of the fire. In all investigations, the total available information must be considered before coming to a conclusion about the wiring. Additional information on this subject can be found in reference (2).

To illustrate what can happen when an insulated cable overheats, figure 4.4.4.1-2 illustrates burning nonmetallic sheathed cable. The flame is due to the burning of electrical insulation.

Ignition will not necessarily occur every time there is a short circuit and overcurrent protection fails. If the current and heat are high enough, as described above, the wire may melt quickly. The development of a fire depends on whether the wires are insulated, what combustibles are present and how close they are to the heat being developed.

Overheating, which is not sufficient to melt the wire or operate the fuses or breakers, may cause breakdown of the wires' insulation. The gases given off by the decomposition of the insulation may be flammable and, if ignited and not concealed, may be the source of the colorful description of "fire racing along the electric wires".

With a fault to ground and loss of fuse or circuit breaker protection, about 150 amperes will produce the effect in BX cable shown in figure 4.4.4.1-3. It is obvious that there are parts of this cable armor (figure 4.4.4.1-3) which are hotter than other parts. The same current is going through the entire piece of cable armor. The cable is hotter where it is straight than it is where it is curved because the spirals are in tighter contact with each other where the cable is curved. Where the spirals are in tight contact, resistance or impedance is lower. Where resistance is lower, the cable armor is not as hot.

In addition to fault currents, overloaded circuits may cause conductors to overheat. A circuit is overloaded when the total current being drawn exceeds the capacity of the wire. The only protection against overloaded circuits is fuses or circuit breakers.

If the overload protection does not function for one of the reasons stated previously, the heating may continue. This sets the stage for a short circuit as the insulation softens and distorts, ultimately permitting contact between the hot wire and the neutral. Insulation also deteriorates with age. This is particularly true of the rubber insulated wires installed before 1950. Often the insulation will be so brittle that it breaks if the wire is flexed. The combination of deteriorating wire, inadequate electrical supply service for today's needs, and "correcting" the problem by using oversized fuses, makes the wiring in an older home or building a prime suspect for a fire with no other rational explanation.

The problems resulting from overfusing appear principally in older houses with edison-base fuses as edison-base fuses have not been permitted in more recent installations. Fifteen, 20, 25 and 30 ampere fuses can be readily purchased and used in edison-base fuseholders. The vast majority of these circuits should be fused for either 15 or 20 amperes. Generally, #14 copper wire should be fused no more than 15 amperes, and #12 copper wire should be fused at no more than 20 amperes. Very few branch circuits, other than those for special purpose, high-wattage equipment, such as electric water heaters, electric ranges, electric furnaces and central air conditioning units, have wires larger than #12.

While overfusing is probably more prevalent with edison-base fuses, it should not be assumed that circuit breakers and type S fuses have been properly matched to the wire size. When fires are suspected of being electrically-caused, information on the sizes of fuses or circuit breakers should be obtained, along with the gauge (size) of the wires connected to them, and used in determining what happened (see table 4.5.10-1).

Fault currents or overloaded circuits are not the only reasons for conductors to overheat. An example of this is where stranded wire is connected to an appliance, such as an electric range. If one or more of the strands break, there could be insufficient wire capacity remaining for the current in the unbroken strands. This could cause overheating at the break during normal current demand for the electric range.

4.4.4.2 On-line arcing/sparking

Another potential mechanism for causing fires is on-line arcing/sparking. Sometimes when one throws a switch "ON" or "OFF" or inserts or withdraws a plug from a receptacle, a small spark will be observed. This mechanism does not involve short-circuits.

When the spark is momentary, it is quite harmless in a normal environment. However, if it occurs in certain hazardous environments, such as where flammable vapors or combustible dusts are present, this spark could set off an explosion. The National Electrical Code requires

special switches, receptacles and other components, in hazardous environments. The electrical protection for these hazardous environments must be perfect; a single breakdown or omission in the system can cause an explosion. If a fire or explosion has taken place in such a protected area, the investigator should seek expert assistance. As the hazardous environments referred to above are typically found in only certain industrial plants, the fire investigator is not likely to encounter this situation with any great frequency.

If a connection is loose and the wire is rapidly making and breaking contact at the connection, possibly caused by vibration, there will be repetitive arcing/sparking and the connection will heat up rapidly. Within minutes the metal in the vicinity of the connection may become hot enough to ignite nearby combustibles. Severe repetitive arcing/sparking may not only discolor the wire but may also result in pitting or surface damage to the wire as small metal particles are removed.

4.4.4.3 Glowing connections/glowing contacts

This ignition mechanism also does not result from fault currents or overloaded circuits. It is almost always a result of poor connections. Fuses or circuit breakers do not provide protection from this phenomena.

Figure 4.4.4.3-1 shows an example of a glowing electrical connection. Glows may occur at loose connections or at points in the current path where loose contact is made, such as a broken part of the wire. Glows may occur with aluminum wire or copper wire or with other metals used as conductors, such as steel in a wire connector or in cable armor. In the case shown, the load is plugged into another receptacle which is downstream, or electrically beyond this receptacle (3).

In the laboratory, glows have lasted as long as 129 hours. Glowing connections can occur virtually throughout the entire range of currents common in residential wiring. With 15 amperes in a circuit, as much as 30 or 35 watts can be dissipated at a glowing connection. With 0.8 of an ampere in the circuit, about 5 watts can be dissipated at a glowing connection.

Figure 4.4.4.3-2 shows a receptacle in a nonmetallic outlet box where a glow had been sustained for about two hours. In this case the metal current path was still intact. Except for discoloration, there was little damage to the wire or the metal components in the receptacle.

4.4.4.4 Exploding wires/exploding contacts

When very high currents are passed through conductors with a small cross sectional area, the conductors may literally explode and spray molten pieces of metal in all directions.

Low impedance electrical faults may produce currents high enough to explode wires. For example, 500 or more amperes will explode a #22 copper wire. However, in buildings it would seem that exploding contacts, as opposed to exploding wires, are more probable. Shown in figure 4.4.4.4-1 is a nail being driven into a cable so that the nail contacts both the ungrounded or hot wire and the grounding wire. The points where the nail contacts the wires are exploding and spraying small pieces of molten metal in all directions. This illustrates the term "exploding contact". Figure 4.4.4.4-1 is a time exposure of an exploding contact. It all happens in less than 1/60 of a second. Each of the streaks is the path of a piece of molten metal.

If there are combustibles in the vicinity of these pieces of molten metal, the combustibles may ignite. During laboratory experiments, pieces of paper which identified tests, as well as deliberately placed combustibles, were ignited from the sprayed molten metal.

The significance of this phenomena is that it can happen before fuses or circuit breakers operate. With exploding contacts, there will be definite damage, such as metal blown out of wires, nails, or other objects.

4.4.4.5 Overheating nonmetals (high resistance faults)

A high-resistance fault can result when current is passed through a nonmetallic but semi-conducting material. The resistance of small lengths of some nonmetals may be such that under fault conditions, currents may not be high enough to operate fuses or circuit breakers but are high enough to ignite the nonmetallic material. One experiment done at the National Bureau of Standards (NBS) was to stuff cellulose insulation into an electrical outlet box. When the cellulose insulation was soaking wet, as much as 100 watts of power was dissipated between the ungrounded or hot conductor and the grounded outlet box.

4.4.4.6 Arc-Faults

Fires have been caused by arc-faults. They usually involve 480/277-volt, "Y" connected, distribution systems. These faults are known as "arcing ground faults" and are caused by high-voltage breakdown of the air gap between a conductor and ground or between two electrical phases of a three-phase distribution system. The air gap between one phase and ground or phase-to-phase can be bridged by dirt, coupled with moisture, or by accidental causes such as the dropping of metal across a conductor and ground or across two conductors at different voltages. Once the arc is struck, it tends to continue due to the ionizing of the air in the vicinity of the arc (the air becomes conductive). In many cases, the current being drawn by the arc is less than the setting of the overcurrent protection in these systems, even though the current may be on the order of several thousand amperes. The result is that massive

damage to the equipment and ignition of the nearby combustibles can occur before the fault burns clear, or becomes the kind of fault that the overcurrent device can "see" and react to.

A theory is that an arc struck at voltages over about 370 volts AC will be self-sustaining, while arcs struck at lower voltage levels will self-extinguish. For this reason, arcing faults tend to occur in building power distribution systems at a point after the utility company's transformer (which are usually supplied at higher voltages) and before the smaller transformers within the building which provide the 120-volt electricity for receptacles and equipment from the 480/277-volt distribution system. Because of the specialized and complicated nature of the equipment used in the higher voltage, three-phase distribution systems, help from specialists should be sought if arc faults are thought to be the cause of the fire.

4.4.4.7 Other Electrical Failure Modes

A distant short-circuit can send high currents over the grounding conductor, which, in figure 4.4.4.7-1, is the armor of a BX cable. In this photo, a plug in another location has been shorted. Wherever the cable contacts grounded metal, which in this case is foil-faced thermal insulation, some of the current will flow through the grounded metal. If the contact between the armor and the grounded metal is insufficient to carry the current, the contact may explode. If there are combustibles in the vicinity, the small pieces of molten metal being sprayed around may ignite them. In this case, 3 or 4 square inches of foil was blown off the insulation, but the paper backing is not discolored, so an electrical problem is not readily apparent.

This phenomenon can be illustrated by a simulated situation. In figure 4.4.4.7-2, the armor of the BX cable is in contact with a grounded heated duct. If a short circuit occurs, the BX cable will be either welded to the heating duct (a low resistance but structurally weak connection) or blown away from it. If welded to the heating duct, the BX cable could stay that way indefinitely without causing any harm. A hazard could result if another short circuit occurs which causes the weld to explode, resulting in molten metal being sprayed about. If the BX cable is blown away from the heating duct, there may be only slight damage visible on either the surface of the cable or the surface of the duct, and this damage could easily escape detection during a fire investigation.

Another possible way for a fire to start in a place distant from the point of electrical fault involves a glowing condition resulting from a poor "grounding" conductor connection which is forced to carry some current because of an unintentional connection to the white (neutral) wire. For example, if the neutral conductor to an appliance, such as a washing machine, was accidentally connected to grounded frame of the machine, current would return over the grounding path. A glow could result at a distant point in the grounding path, such as at a faulty fastening between the armor of a BX cable and an outlet box, as shown in figure 4.4.4.7-3. In this photo, the kraft paper, which is inside the BX cable between the insulated conductors and the metal armor, has ignited.

4.4.4.8 Aluminum Wiring Fires

The introduction of aluminum wiring into buildings as a substitute for copper wire has led to a great deal of controversy over the relative safety of aluminum-wired electrical systems. The U.S. Consumer Product Safety Commission on October 26, 1977 filed an action in Federal Court in the District of Columbia against 26 manufacturers of aluminum wire and devices used in 15 and 20 ampere residential aluminum wiring systems generally between 1965 and 1973. The Commission asked the Court to declare these "old technology" systems to be an imminent fire hazard. It also sought an order requiring the defendant manufacturers to give widespread public notice of the hazard and to repair the wiring systems.

The defendant manufacturers have contested the jurisdiction of the Commission to bring this action. The proceedings to resolve this threshold question have been in progress since the action was filed in 1977. Because of the delays inherent in the litigation, the Commission cannot project when this case will be resolved. In the meantime, the Commission has urged the public to immediately take the necessary steps to have their wiring systems repaired to protect their lives and property. The necessary steps are outlined in a booklet entitled, "Was Your Home Built After 1964? Do You Have An Electrical System With Aluminum Wiring?" This booklet may be obtained by calling any of the following toll-free hotline numbers: in the Continental United States call 800-638-8326; in Maryland call 800-492-8363; in Alaska, Hawaii, Puerto Rico, or the Virgin Islands, call 800-638-8333.

If there is an investigation of a fire which involves a 15 or 20 ampere aluminum wiring system which results in death or personal injury, the Commission would appreciate a call regarding the incident.

4.4.4.9 Panelboard Fires

The National Electrical Code (NEC) defines panelboards as a panel which includes bus-bars and automatic overcurrent devices for the control of light, heat or power circuits. In addition, the panel is to be placed in a cabinet and the cabinet mounted against a wall or partition. And, finally, the panel is to be accessible only from the front.

Lighting and appliance branch circuit panelboards, the most typical, may have up to 42 branch circuits and overcurrent devices, not including the mains overcurrent devices. In single family residences, the mains overcurrent protection devices are typically in the panelboard. In apartment buildings, office buildings, and similar occupancies, the mains overcurrent devices may or may not be in the panelboard.

Fires in panelboards do occur, though the frequency of such fires, as compared to fires in other parts of the electrical distribution system, is not accurately known. Fires in panelboards can be quite destructive due to the large currents typically available. As an example, a 200-ampere panelboard can supply up to the 200 amperes in the event of a fault within the panelboard enclosure.

A typical fire in a panelboard might originate as a failure of one of the branch circuit breakers to open under a low impedance-fault somewhere in the downstream side of the system. Failure of the circuit breaker to operate for fault conditions could be due to relaxation of the springs within the breaker, burrs or sharp projections on internal parts which could cause the breaker to hang-up, or improper assembly of the breaker itself. Failure of the breaker to operate results in overheating in the circuit at the point of highest impedance (resistance) and this is often within the breaker itself. What happens at this point is that the breaker is destroyed by the heat which, in turn, opens the circuit. If the access door to the panelboard is closed and/or there are no nearby combustible materials present, the problem is over. However, sometimes heat from the breaker results in damage to other components within the panelboard producing subsequent faults. One such incident now will be described.

The fire originated in the electrical room in the basement of a garden-type apartment building. The fire caused extensive damage to the electrical equipment within the room, as well as to the room itself, and had begun to penetrate the ceiling into the apartment above when extinguished. Upon clearing away the debris, the fire was found to have originated in a panelboard used to supply 240-volt circuits to individual air conditioners in each apartment. Figure 4.4.4.9-1 shows the condition of the panelboard before disassembly. Note the elongated holes burned through the face and side of the steel enclosure. Figure 4.4.4.9-2 is an interior view of the panelboard enclosure. Note the extensive damage to the two circuit breakers, which were ganged (tied together), located in the upper corner of the right hand breaker bank.

The panelboard contained smaller-sized, branch circuit conductors, originating at the circuit breakers, and larger-sized feeders, which supplied the panelboard. In figure 4.4.4.9-3, both the branch circuit conductors and two feeders are visible. Note that the feeders, which pass along the right side of the panelboard, have a section missing in the vicinity of the holes in the cabinet (see circled area) and that the missing portions of the feeders match the length of the holes in the cabinet. Figures 4.4.4.9-4 is another view of the panelboard, with the front removed.

In pinpointing the cause of the fire, it was deduced that there was a low impedance fault somewhere in the circuit served by the ganged twin breakers in the upper right corner of the panelboard (see figure 4.4.4.9-2). A defect in one of the breakers prevented the breakers from functioning and opening the circuit. Overheating took place within the breakers. This heating caused the insulation on one or both of the feeders in close proximity to the breakers to soften and fail, allowing the now partially-bare feeder or feeders to ground to the metal cabinet. The resultant high current was sufficient to burn the holes in the steel cabinet. The molten steel from the arcing was thrown about the room, setting fire to other combustibles located in the electrical room.

The possibility of an aluminum wiring problem had to be considered as the branch circuit conductors were aluminum. The aluminum conductors are visible in figure 4.4.4.9-3. The color differences between the aluminum branch circuit conductors and the copper feeders may not be clearly evident to the untrained eye due to the limitations of black and white photography. The faulty circuit breakers were disassembled whereupon it was found that the aluminum wire connectors to the breakers were intact and sound, indicating no problem with the aluminum wiring (see figure 4.4.4.9-5).

Recapping this fire in terms of a fire investigation procedure, the origin of the fire was easily determined to be the electrical room in the basement of the garden apartment building as the fire damage was confined to this room. The room's function pointed towards an electrical fire as the most probable cause. Discovery of the melted holes in one panelboard's steel enclosure confirmed the cause as electrical. Determining why the electrical fault occurred within the panelboard took some time and a certain amount of deduction. What could not be determined was what had happened on the branch circuit served by the ganged twin circuit breakers to cause their attempted operation and subsequent overheating. The damage was so extensive to the wiring in the electrical room that the circuits could not be traced. As discussed in previous parts of this chapter, it is possible for an electrical problem in one location to cause an electrical fire in another location remote from the originating fault. This case is an example of that point.

4.4.4.10 Some Helpful Hints

Electrically-Caused Damage

- Pitting of wire or connectors
- Metal splatter (from melting)
- Insulation no longer bonded to wire (Sagging, drooping, brittle)
- Balling of copper at end of wire (Sometimes fire caused)
- Melting of conductors (Sometimes fire caused)
- Fusing together of wire strands (Sometimes fire caused)

Fire-Caused Damage

- Melted wire with pointed ends
- Insulation tightly bonded to wire (Burned externally)
- Necking down of wires (Reduced cross section)

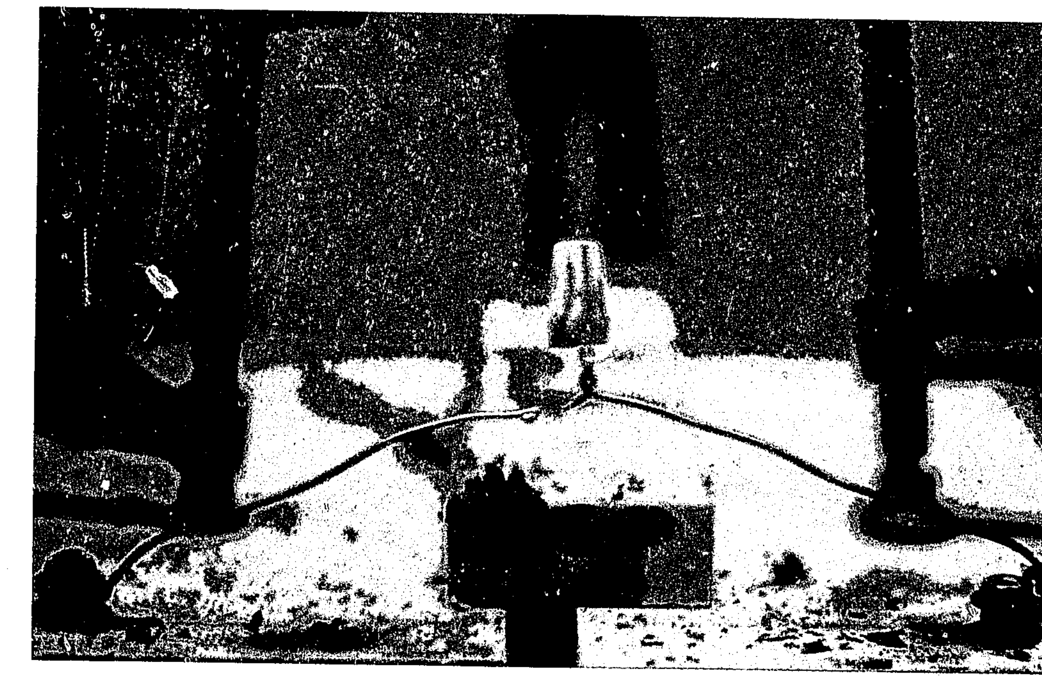

Figure 4.4.4.1-1

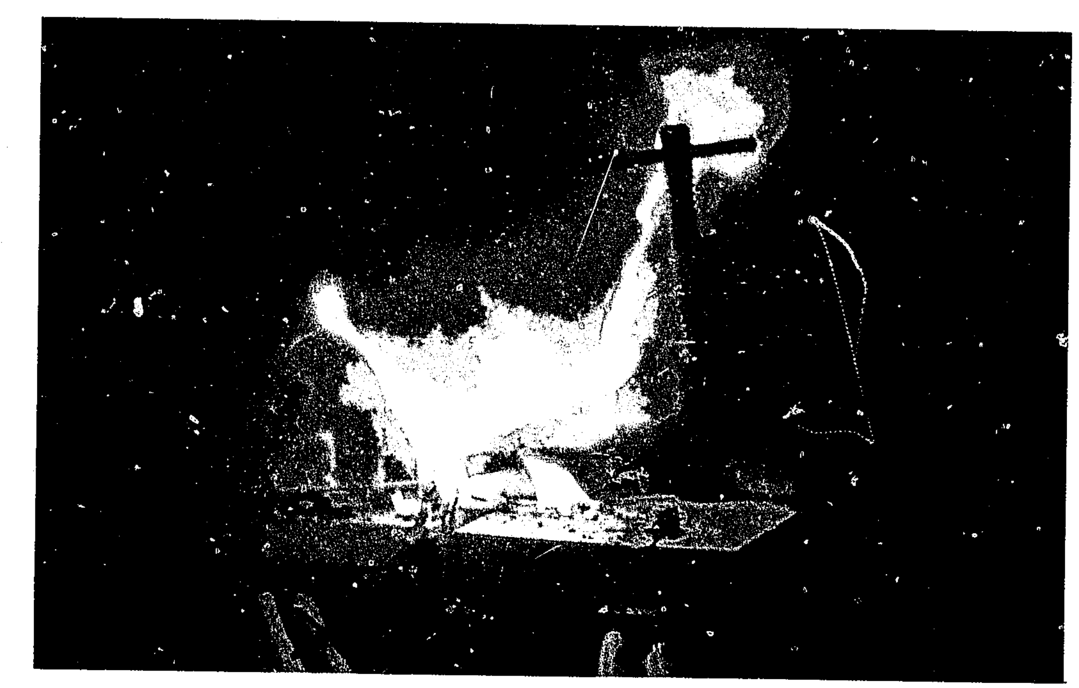

Figure 4.4.4.1-2

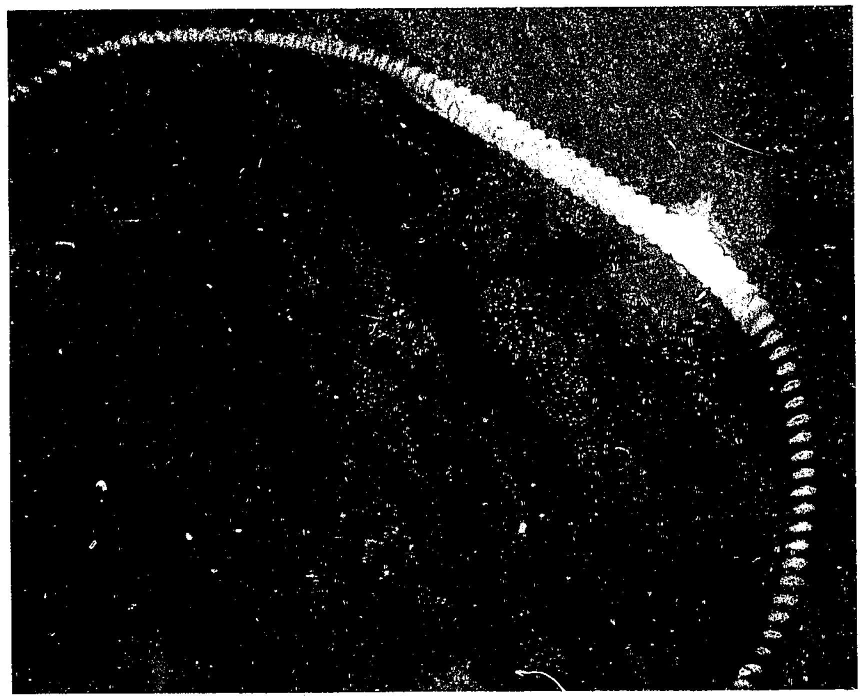

Figure 4.4.4.1-3

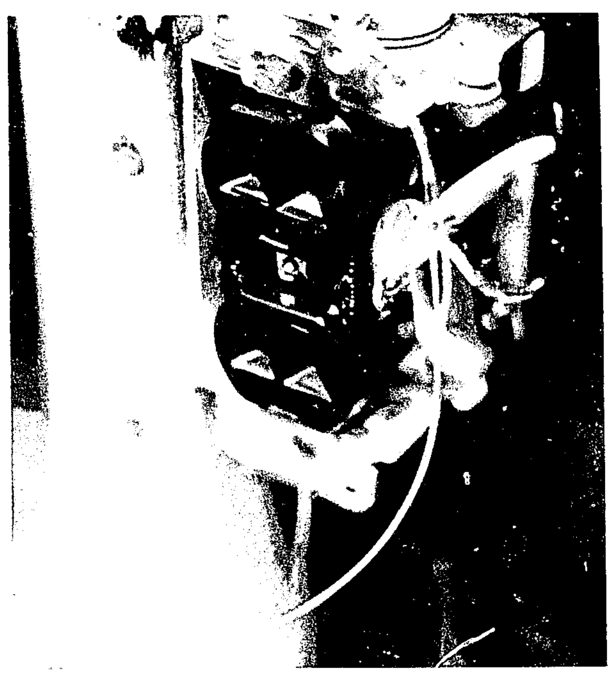

Figure 4.4.4.3-1

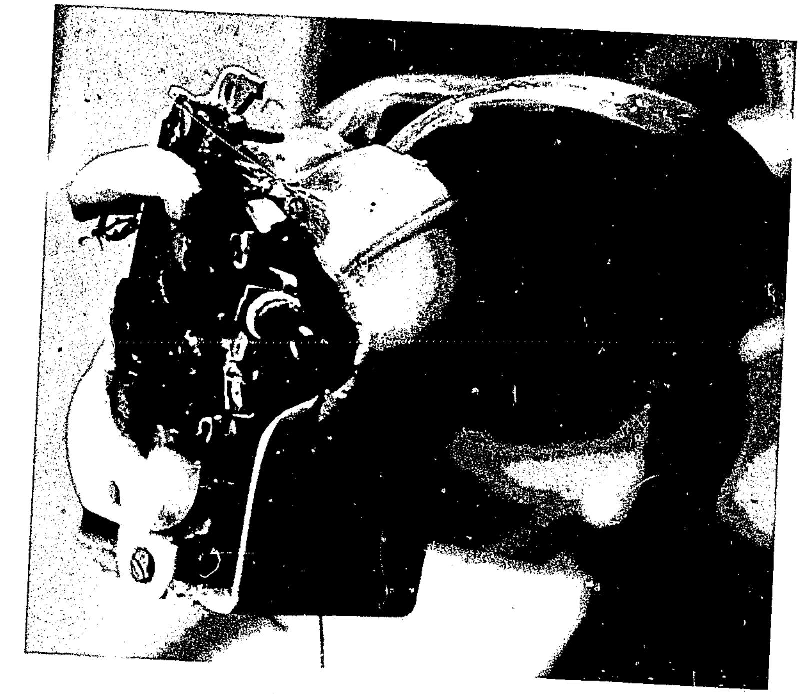

Figure 4.4.4.3-2

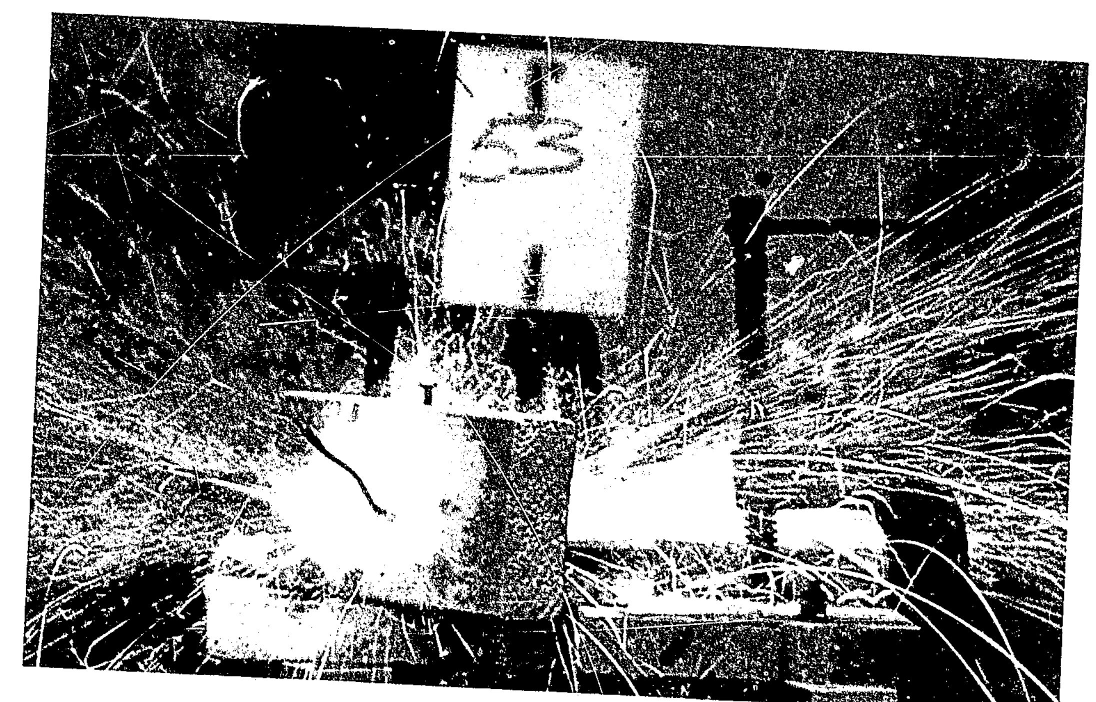

Figure 4.4.4.4-1

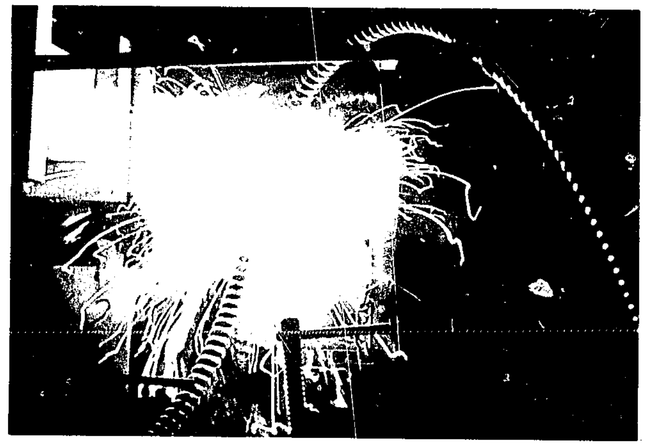

Figure 4.4.4.7-1

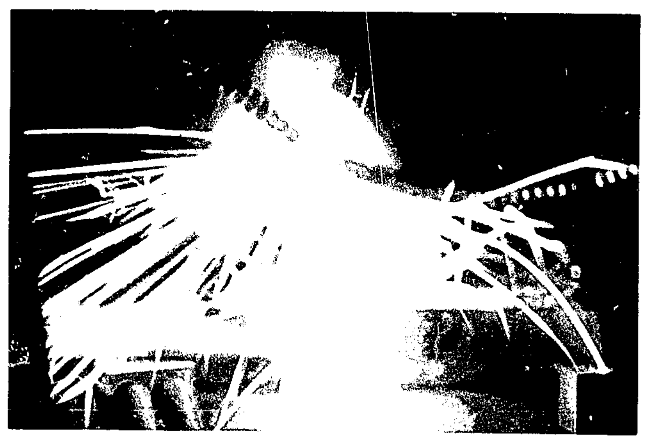

Figure 4.4.4.7-2

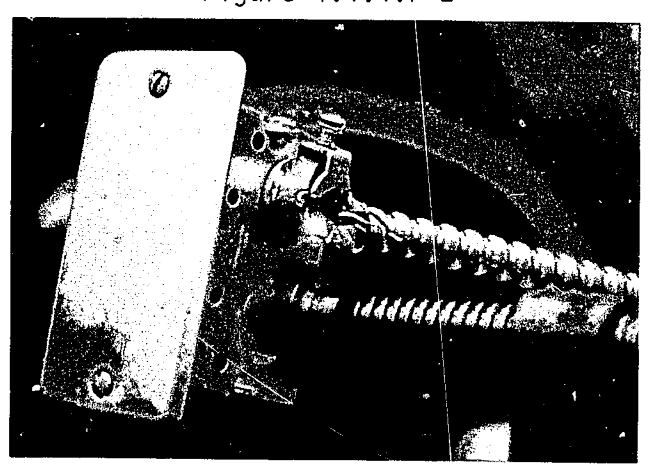

Figure 4.4.4.7-3

Figure 4.4.4.9-1

Figure 4.4.4.9-2

Figure 4.4.4.9-3

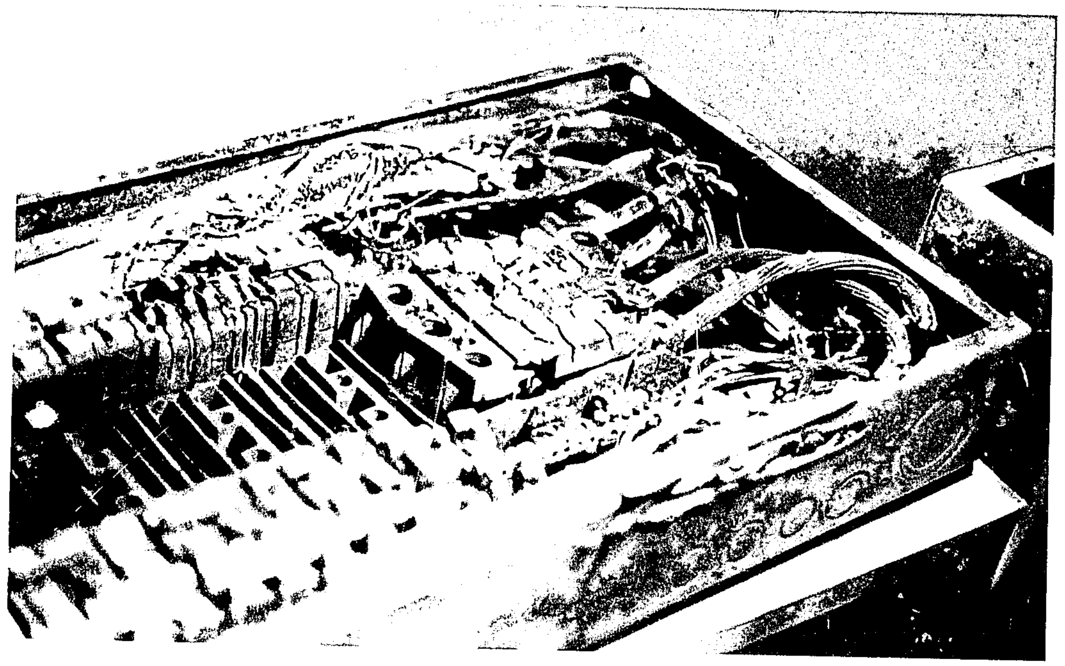

Figure 4.4.4.9-4

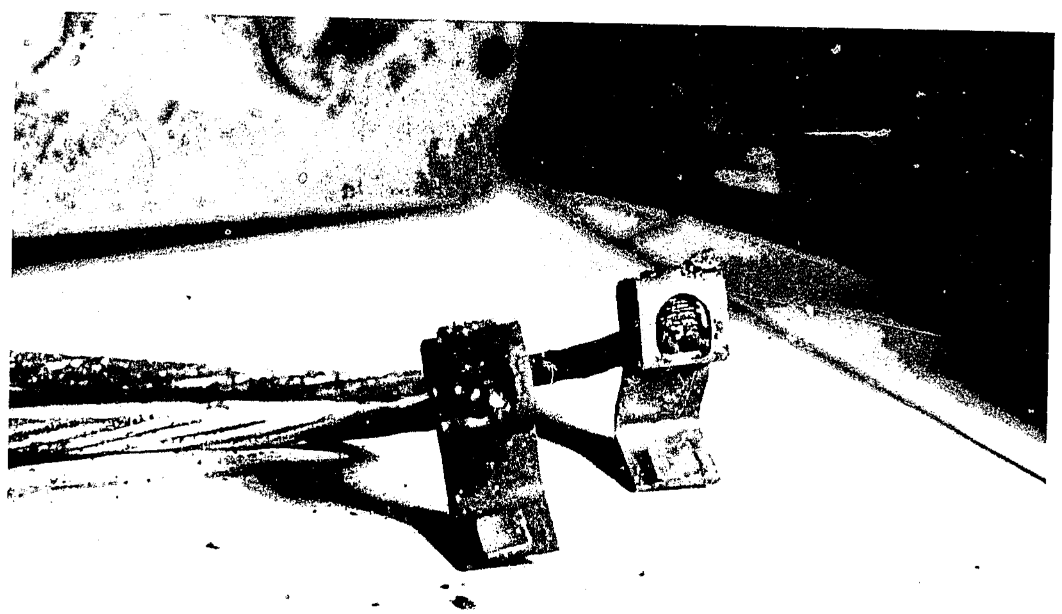

Figure 4.4.4.9-5

4.4.5 Electrical Appliances and Electrical Fixture Fires

4.4.5.1 Introduction

Electrical appliances and electrical fixtures are responsible for a relatively small but still significant number of fires each year in the United States. There are many ways appliances and fixtures can cause fires, too many to be discussed here item-by-item. However, there are some general principles which the investigator should keep in mind and these will be discussed here.

4.4.5.2 Electrical Appliances

From a fire investigatory standpoint, electrical appliances can be divided into two categories: those appliances which produce and utilize significant quantities of heat for some specific purpose, such as comfort heating or cooking and those appliances which do not. In the heat-producing category are such appliances as:

1) <u>Electrical Appliances Producing Significant Heat In Normal Use</u>

   a) Portable electric heaters;
   b) electric blankets and heating pads;
   c) electric clothes irons;
   d) soldering irons;
   e) cooking ranges;
   f) table-top ovens/broilers;
   g) toasters;
   h) deep-fat fryers;
   i) clothes and hair dryers;
   j) electric griddles and fry pans.

Examples of electrical appliances which perform a function other than the production of significant heat are:

2) <u>Electrical Appliances Which Do Not Produce Significant Heat</u>

   a) Television receivers, radios, high fidelity sound equipment;
   b) food mixers, grinders, blenders, processors;
   c) electric clocks;
   d) washing machines;
   e) vacuum cleaners;
   f) window air conditioners.

In category no. 1, the heat that is produced is a product of passing an electrical current through a resistance. In some of the appliances, the heat output is controlled or regulated by a thermostat or other device, so as to remain within a "safe" operating range (electric blankets, heating pads, irons, deep-fat fryers, for example). In other appliances, the heat produced is not controlled but is maximum for the current/resistance combination of the appliance. Because of the high heat produced in these appliances, guarding, shielding, fan cooling, or careful placement of the heating element are used to prevent accidental ignition of nearby combustible materials (portable electric heaters, toasters, clothes and hair dryers, cooking ranges, for example).

In general, there are four failure modes in these heat-producing appliances which may lead to fires. These are:

1) The heat regulating mechanism fails, allowing an overheat condition to develop (for example, thermostat failure in a deep-fat dryer).

2) Combustible materials are brought too close to the appliance (for example, clothes draped over a chair in front of an electric heater).

3) The appliance is installed or used without adequate clearances to combustible materials (for example, table-top broiler used on the kitchen counter under wooden kitchen cabinets).

4) Shielding installed to prevent transmission of heat to adjacent surfaces is removed or defeated (for example, removal of the metal plate on the bottom of a hotplate allowing the heating coil to radiate downward as well as upwards).

With respect to thermostatically-controlled appliances, if the appliance is thought to be the cause of the fire, check the thermostat, either visually or with an ohmmeter. If the thermostat is open, the probability the appliance caused the fire is low. If, however, the thermostat is closed, the probability the appliance caused the fire is increased.

Some appliances have a backup or secondary thermostat which is used for extra safety (gun-type hair dryers, for example). These backup thermostats are usually spring-loaded, fusible elements. If they fuse due to an overheat condition, the thermostat opens. Check these thermostats with an ohmmeter. If open, it is highly unlikely the appliance could have caused the fire.

Category no. 2 appliances, those which do not produce heat in significant quantities during normal operation, are less frequent sources of ignition. One exception to this is television receivers which, in the past, have been responsible for a relatively large number of fires.

In category no. 2, there are two kinds of appliances, those which use electronic circuitry to accomplish their function and those that use motors. Television receivers, stereo systems and radios use electronic circuitry. Electric clocks, washing machines, food mixers, and food

processors use motors. Motors in appliances rarely cause fires which extend beyond the appliance. In the case of the electronic equipment, most problems occur at the power entry end of the equipment, which usually involves a transformer and its' associated filtering capacitors. Failure of a capacitor can produce a heavy load on the transformer resulting in overheating and an eventual fire. Examination of the transformer will usually reveal whether the transformer caused a fire or was damaged by exposure to a fire. If the transformer's insulating varnish appears to have boiled out of the windings, this is a sign of an overheat condition. On the other hand, if the varnish is blistered on the outside but without the appearance of having boiled up out of the windings, then the transformer has been exposed to the fire but it was not the cause. Even if the transformer has been severely damaged in the fire, careful examination of the core and the insulating varnish will often disclose whether the fire originated in the transformer or that the transformer was merely exposed to the fire.

With regards to television receivers and their fire problems, one study estimated that in 1973-1974 (April 1, 1973 to April 15, 1974) there were some 200,000 television receiver fires out of a total of 4,500,000 hostile fires in homes (4). Another study has indicated, however, that in terms of the number of fires, per year of manufacture, black and white sets peaked in 1974 and have been dropping ever since while fires in color sets peaked in 1970 and have been on the decline since 1970 (5). Thus, for the fire investigator, the probability that a television receiver was the cause of the fire is declining, with older sets being more likely to cause fires than newer sets.

The so-called, "instant-on" television receivers have had a reputation for causing more fires than sets without this feature. These sets have certain circuits which remain powered, even when the main power switch is off. Nearly all of the instant-on sets utilize vacuum tubes with relatively high power demands. Vacuum tubes have been largely replaced with solid-state components in current television receivers. Solid-state components require very little warm-up time and consume little power.

In summary, each appliance has distinctive methods of failure which may produce a fire. The fire investigator will need to exercise a certain amount of ingenuity in determining whether an appliance was or was not the cause of the fire and, if so, how. Comparison of the appliance in question with a similar or identical, undamaged appliance can be helpful. Even so, investigators may need to seek expert advice, from time-to-time, from persons familiar with electrical and electronic principles in general, as well as the particular appliance in question.

4.4.5.3 Electrical Fixtures

As used in this section, electrical fixtures are lighting fixtures and include both incandescent and fluorescent lighting fixtures.

Lighting fixtures installed on a ceiling may be:

1) Recessed into the ceiling;

2) installed flush with the ceiling's surface;

3) surface mounted on the ceiling's surface;

4) suspended from the ceiling (pendant, stem-mounted, etc.);

5) other (cove lighting, in exhaust hoods, etc.).

While "recessed" and "flush" are shown as separate categories, for all practical purposes, they are and will be treated as the same. Recessed/flush fixtures are those fixtures installed above the ceiling's surface which project their light downward through a hole in the ceiling. Surface-mounted fixtures are fastened directly to the underside of the ceiling. Suspended fixtures are installed below the ceiling and are fastened to the ceiling via stems, tubes, chains, or their own power conductors (pendant fixtures).

Fixtures using incandescent lamps produce heat, sometimes in significant amounts (heat lamps in bathroom ceilings, for example). If the fixture is not able to get rid of the heat safely, an overheat condition, and a fire, may result. The National Electrical Code (NEC) states that flush/recessed fixtures shall be so constructed and installed that adjacent combustible materials will not be subjected to temperatures in excess of 194°F (90°C). For fixtures recessed in fire-resistant materials in buildings of fire-resistant construction, temperatures up to 302°F (150°C) are permitted. These requirements are straightforward but it is difficult to determine that they have been met after a fixture has been installed. The NEC handles this by requiring that the fixture be at least 1/2-inch away from combustible materials other than at the point of support. Thermal insulation is to be not closer than 24 inches over the top or closer than 3 inches to the sides of the recessed fixture's enclosure or wiring compartment (junction box).

One other requirement applying to fixtures is the type of wiring permitted within the fixture. The wiring is called "fixture wire" and its use is permitted only within fixtures. For example, it cannot be used for branch-circuit conductors. Further, and this is important, each fixture wire is rated for a specific temperature operating range. Thus, if a fixture wire is suitable for a temperature operating range of 140°F (60°C), the wire cannot be used in a fixture where the temperature operating range exceeds 140°F (60°C). A fixture wire with a higher temperature operating range must be used instead.

Some of the things that can happen to turn a safely-operating, lighting fixture into an ignition source are:

1) A fixture is installed, recessed into a ceiling, with zero clearances to combustible materials.

2) A fixture is surface-mounted onto a low-density combustible fiberboard ceiling. The fixture is approved for, and operates safely with, a 60-watt lamp. The bulb is changed to 100 or 150 watts to obtain extra illumination.

3) An attic of a house is retrofitted with combustible cellulosic insulation. The insulation contractor blows the insulation into the attic completely covering one or more recessed/flush lighting fixtures.

All of the above have happened and have caused fires. In addition, nos. 2 and 3 may result in degradation of the insulation on the wiring in the fixture due to the increased heat output (in no. 2) or the buildup of heat from lack of adequate ventilation (in no. 3).

Fluorescent lighting fixtures have operating characteristics that differ from incandescent lighting fixtures. The fluorescent tubes themselves are relatively cool during operation. However, the ballasts, which operate the fluorescent tubes, may not be cool. In fact, the NEC requires that ballasts be treated as a source of heat as ballasts have been responsible for a number of fires. If the ballast is installed on a combustible surface and overheats, the ballast may initiate smoldering combustion in the combustible surface. Present NEC requirements are that the ballast be spaced away 1-1/2 inches from combustible, low-density cellulose fiberboard. But there are many installations still existing where this has not been done, simply because the installer was unaware of the requirement or was unable to identify the combustibility of the ceiling material to which the fixture was being attached. There are fluorescent fixtures approved for mounting on these combustible surfaces and they will be so labeled. But, after a fire, the investigator may not be able to find any trace of the label.

Ballasts have been known to explode and spray molten copper in all directions. In one such incident several anxious moments were spent by people running around extinguishing spot fires caused by the molten copper droplets.

Current NEC requirements call for all ballasts to contain integral (internal) protection against overheat conditions. The type of protection used is either a small circuit breaker or a small fuse. Ballasts which contain this internal protection will be marked "Class P". Again, after a fire, the marking may be unrecognizable, though it may be possible to determine whether the internal protection was provided by a visual examination of the ballast. There are undoubtedly many fluorescent fixtures in use which contain older ballasts, those without the internal protection.

The fire problem with incandescent light fixtures usually is one of improper installation, improper operation or inadvertent insulating of the fixture so that normally-developed heat cannot safely escape. The fire problem with fluorescent light fixtures is the ballast. In a fire investigation where fluorescent fixtures are involved, or thought to be involved, the ballasts, and their location with respect to combustible materials, should be carefully examined.

4.4.6 Summary

The determination that the cause of the fire is electrical can vary in difficulty from quite simple to incredibly complex. Fire investigators should know their limitations and not be hesitant to seek expert help when needed. It is also helpful to develop a roster of experts competent in various areas of electrical expertise, such as in explosion-proof electrical systems and appliances.

4.4.7 References

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(4) Buchbinder, B., Survey Results in New Data on Household Fires. Technical News Bulletin of the National Bureau of Standards Dimensions, Vol. 59, No. 1, pp. 10-11, 22, January 1975.

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4.5 CASE STUDY OF AN ELECTRICAL FIRE

4.5.1 Introduction

In chapter 4.4, some of the failure modes in electrical distribution systems, as well as in appliances and fixtures, were reviewed. In this chapter, a detailed case study of an electrical fire investigation in a single-family residence will be presented to illustrate a suggested procedure to be followed in such an investigation. The methods and procedures employed are representative of those which would be used in other occupancies, such as office buildings, mercantile buildings, restaurants, and so on.

An electrical fire investigation can be conducted at two different levels of sophistication. For example, one level would be the simple determination that a fire was electrical in origin based on the evidence of charred wood studs in the vicinity of an electrical outlet box. Another example would be the presence of a partially-destroyed coffee maker under wooden wall cabinets in a kitchen fire. The other level would be to determine the precise mechanism that caused the electrical outlet to ignite the wood studs in the first place, or the failure mechanism that caused a coffee maker to destroy a kitchen. Probably, most fire investigators would choose the second level, if the choice was theirs to make.

For the case study which follows, a typical one-story, wood frame dwelling, without basement, will be used. The dwelling has three bedrooms, a bath, kitchen, dining room, living room, attached garage off of the kitchen, and an attic over the main portion of the house. The floor plan of the house is shown in figure 4.5.1-1. The fire occurred early in the morning in December 1978. The fire alarm was received by the local fire department at 0117 hours. Response time of the fire department to the house was three minutes.

4.5.2 Determining the Area of Origin - Step 1

After arrival at the fire scene, the fire investigator examined the exterior and the interior of the house. The major fire damage was found to be in bedroom no. 2 with smoke damage throughout the remainder of the house. There also was some extension of the fire into the attic. Effective fire fighting by the local fire department limited the fire damage to bedroom no. 2 and to a small area of the attic directly over bedroom no. 2. An examination of bedroom no. 2 disclosed that the heaviest fire damage was centered along the east wall of the bedroom. Much of the gypsum wallboard was missing from this east wall's inside surface (removed by the fire department during suppression activities). Several of the 2" x 4" wood studs in the east wall were exposed. Two of the studs, in the approximate center of the east wall were deeply charred on their inside faces, with the char on one stud starting much

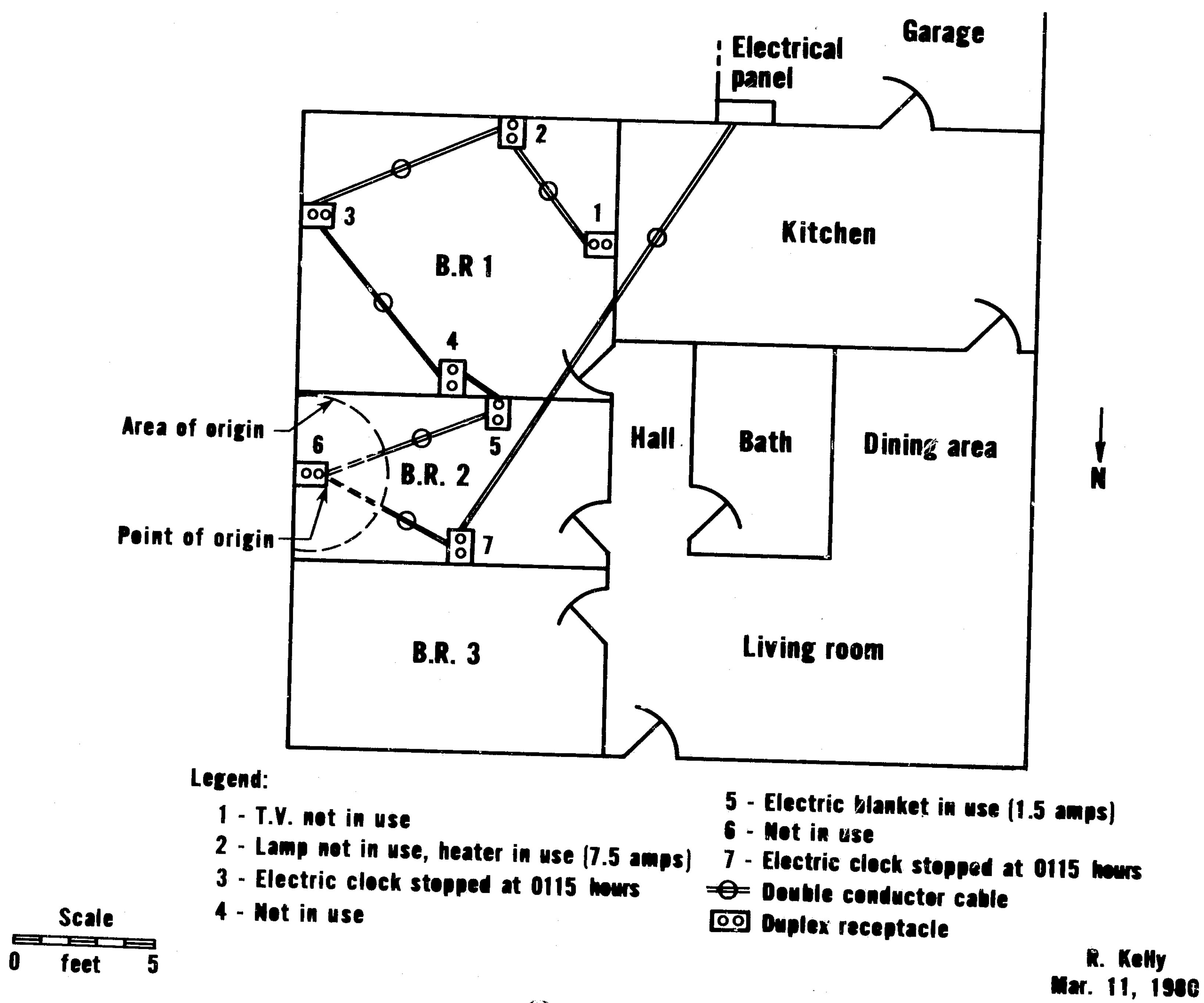

Figure 4.5.1-1

closer to the floor than on the other stud. The extension of the fire into the attic appeared to have resulted from the travel of the fire up the stud channel and through an opening in the 2" x 4" plate at the top of the east wall.

From the physical examination of the fire scene, the fire investigator concluded that the fire originated in bedroom no. 2 with the specific area of origin being the lower portion of the east wall in the approximate center.

4.5.3 Point of Origin - Step 2

From the burn pattern within the stud space, which was readily visible after the fire department's suppression activities, the point of origin was determined to be a point approximately ten inches from the floor on the inner face of the stud with the lowest (closest to the floor) char pattern. The next step was to determine whether any electrical equipment was at the point of origin. Some of the electrical items the investigator looked for were:

1) Receptacles;

2) cables or wiring;

3) TV antenna jacks;

4) TV antenna rotator jacks;

5) telephone jacks.

In this case study, the investigator found the partial remains of a bakelite receptacle box nailed to the 2" x 4" wood stud approximately ten inches from the floor. The remains of the receptacle, the yoke and two sets of binding screws were found in the debris on the floor. The investigator made note of this fact in the notebook. In addition, color photographs of the receptacle showing its location with respect to the stud were taken. Also, the investigator prepared a sketch of the east wall and the location of the receptacle.

4.5.4 Visible Evidence - Step 3

The receptacle parts were examined for arcing, pitting, welding, and melted or splattered metal on the receptacle parts, such as on the yoke and wire binding screws. Most of the plastic parts of the receptacle had been destroyed by heat. The investigator found signs of pitting on the underside of the binding screws (figures 4.5.4-1 and 4.5.4-2), on the base plate (figure 4.5.4-3) and a small portion of the yoke had been burned away (figure 4.5.4-4). The investigator now had evidence that an electrical fire probably had taken place, but more proof was needed.

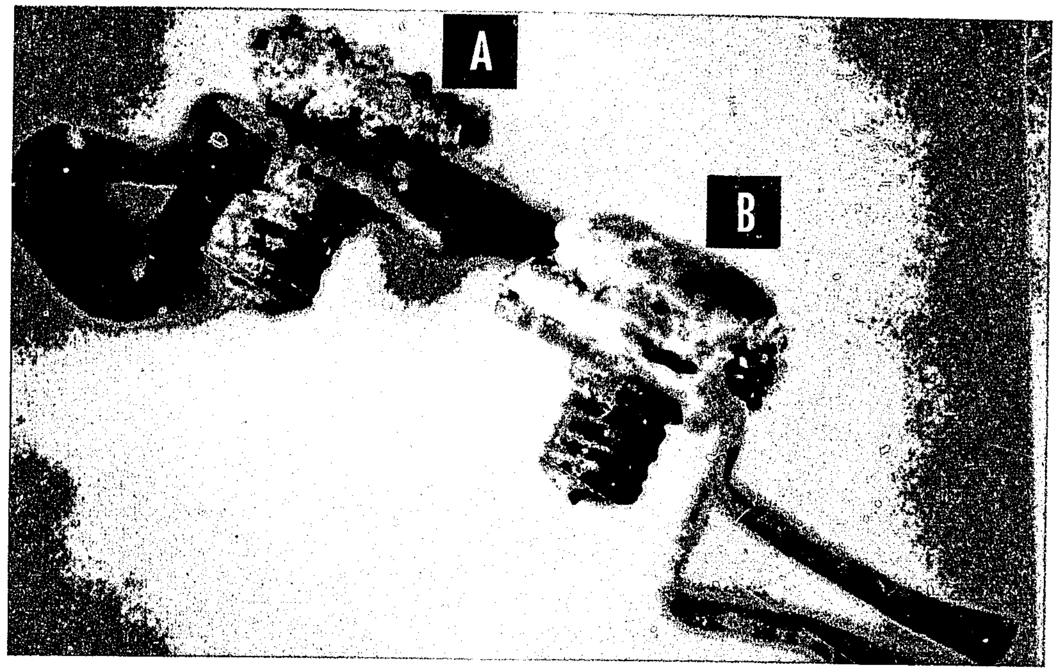

Figure 4.5.4-1

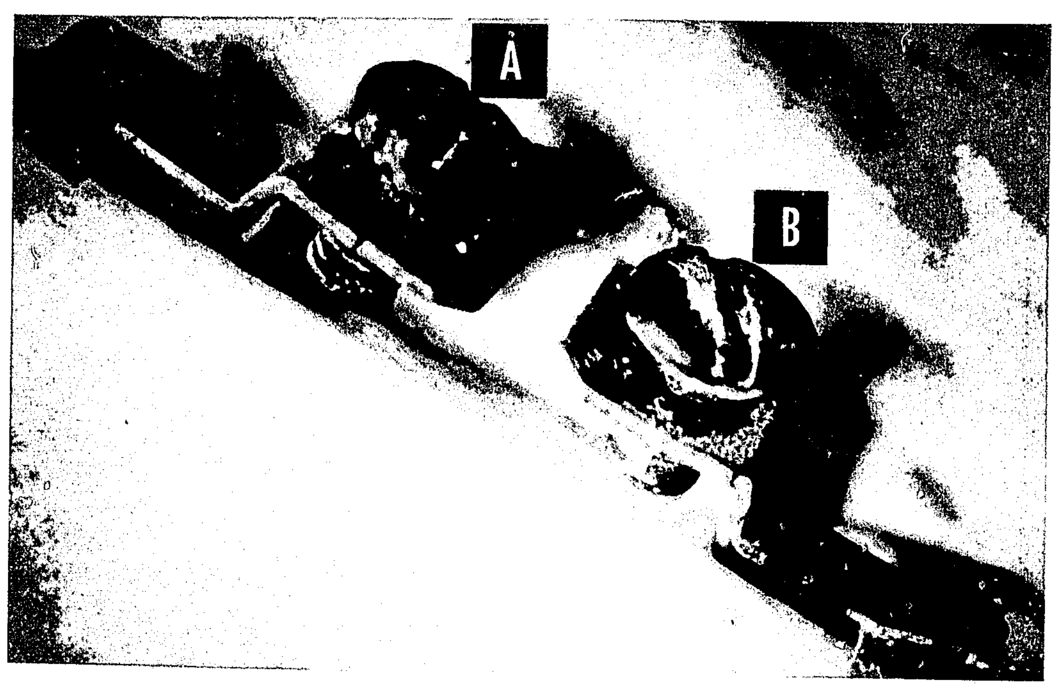

Figure 4.5.4-2

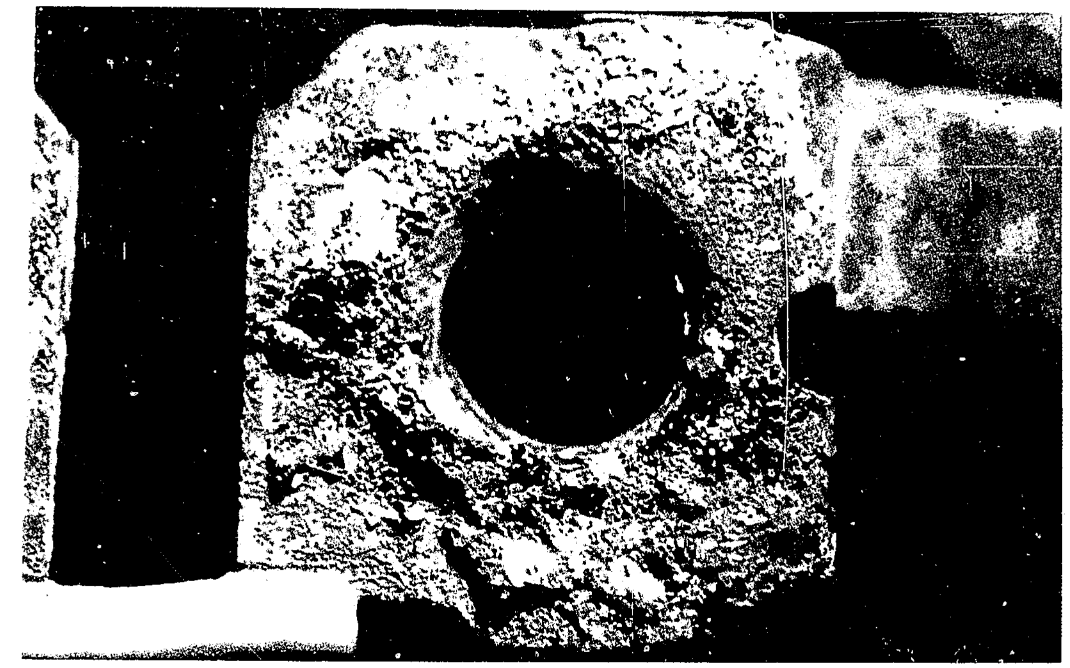

Figure 4.5.4-3

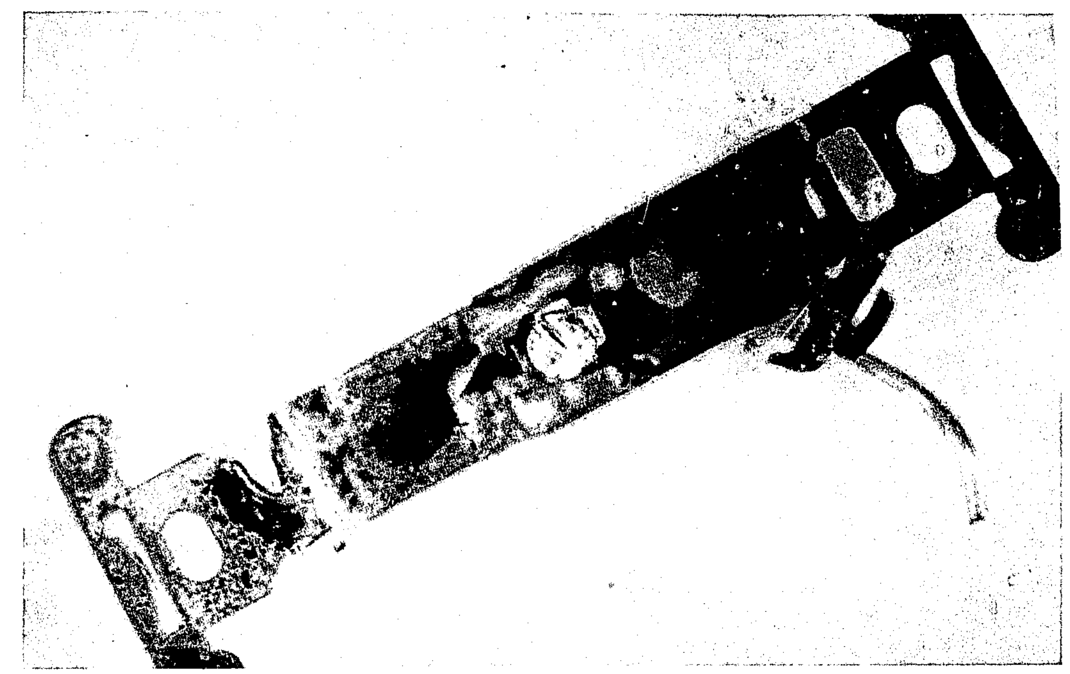

Figure 4.5.4-4

4.5.5 Electrical Service Equipment - Step 4

Next, the investigator proceeded to the garage to check the condition of the electrical service equipment, specifically, the panelboard, for evidence of blown fuses or tripped circuit breakers. The panelboard was found to contain several 15-ampere and one 20-ampere circuit breaker, as well as a main circuit breaker. The investigator found that one of the circuit breakers was in the "tripped" position. All of the remainder of the branch circuit breakers were in the "ON" position. The main breaker was in the "OFF" position. (The main breaker had been turned off by the fire department during its suppression activities.) A color photograph was taken of the panelboard, as found, and appropriate notes were recorded in the investigator's notebook.

In this particular investigation, circuit breakers were the overcurrent protection devices used. Had the panelboard been equipped with fuses, instead of circuit breakers, the investigator would have had to have used a slightly different examination procedure.

Typically, fuses will be of the glass-front variety, usually of 15 ampere capacity with the possibility of some 20 ampere and 30 ampere fuses as well. The fuse link (fusible element) should be examined. If open, the investigator should note the type of separation. A clean break in the fuse link, with no blackening on the inside of the glass front of the fuse, indicates an overload condition which exceeded the fuse's capacity. A blackened glass front indicates a heavy surge of current through the fuse, usually caused by a low-impedance fault on the circuit (short circuit). Also, the investigator should check the inside of all fuseholders for foreign objects, such as pennies, metal washers, aluminum foil, and the like, which may have been used to correct for a constantly-blowing fuse problem. These foreign objects may be found behind good fuses, as well as blown fuses, so all of the fuseholders should be checked.

4.5.6 Panelboard Interior Examination - Step 5

After determining that the power was off, the investigator removed the face cover to the panelboard. The wiring to the circuit breaker (or fuseholders) was examined for signs of overheating (loose or sagging insulation), the binding screws were checked for tightness and signs of overheating (discoloration), the interior condition of the panelboard was checked, and the presence of aluminum wiring, if any, was noted. (Photographs of any unusual conditions also should be taken.) A circuit identification directory was found on the inside of the panelboard access door. The directory identified which circuit breakers protected which circuits. From the directory, the investigator was able to determine that the tripped circuit breaker was on the branch circuit serving bedroom nos. 1 and 2. In addition, the directory could prove helpful later on in tracing circuits, if needed.

4.5.7 Electrical Diagram, Point-of-Origin to Panelboard - Step 6

The investigator now returned to bedroom no. 2 and began to trace the wiring from the bedroom back to the panelboard. As most of the wiring passed through the attic, entry into the attic was made to trace the circuit wiring. An electrical diagram was prepared showing the routes of the wiring, the location of switches, receptacles (and appliances connected thereto), and light fixtures. This was superimposed on the floor plan of the house as is shown in figure 4.5.1-1.

4.5.8 Electrical Diagram, Point-of-Origin Downstream - Step 7

Next, the investigator traced the wiring from bedroom no. 2 in the direction away from the panelboard, or downstream, taking note of all appliances, clocks, lights, and other electrical equipment plugged into receptacles or otherwise connected to the downstream portion of the circuit, and whether these were "on" at the time of the fire. The routing of the circuit wiring to fixtures, switches, and receptacles was added to the electrical diagram shown in figure 4.5.1-1. The circuit tracing revealed that an electric blanket, an electric clock, and an electric heater were connected to the downstream portion of the circuit and were on at the time of the fire. The receptacles to which these appliances were connected are shown in figure 4.5.1-1. The power consumption ratings for the three appliances were: blanket - 180 watts; clock - 5 watts; heater - 900 watts. Thus, the total current passing through the east wall receptacle in bedroom no. 2 prior to and during the fire was approximately 9.0 amperes.

4.5.9 Prior History - Step 8

The investigator checked with the occupants of the house to determine whether there had been a prior history of electrical problems, such as, flickering lights, nonoperative receptacles and switches, frequent circuit breaker tripping (or fuse blowing), and whether there had been any recent electrical repairs or additions and, if so, by whom. The occupants stated that they had had no such problems and no repairs or additions had been made for several years. (Problems revealed by such questioning could furnish clues to the investigator as to possible fire causes.)

4.5.10 Electrical Code Deviations - Step 9

It is sometimes helpful, in an electrical fire investigation, to determine whether the electrical distribution system within the affected structure complied with the local electrical code. The purpose of this examination is not to find fault, but is to ascertain whether there is a pattern of poor practice which may have contributed in some way to the fire. Usually, such an examination needs to be conducted by someone expert in the local electrical code, such as an electrical inspector. In this case study, the fire investigator was such an expert and the investigator conducted the examination by removing a few receptacles and switches from their boxes to see if they were properly installed. The investigator also checked in the attic to see whether wire connections were made outside of junction boxes (a poor practice) and opened several junction boxes in the attic to check the wiring connections for proper splices. In addition, the size of the fuses/circuit breakers in the panel board were matched against the conductor wiring gauges according to the following table:

Table 4.5.10-1 Permissible Currents for Various Wire Sizes (In Amperes)

	Size of Wire			
Type of Wire	#14	#12	#10	#8
Copper Wire	15	20	30	40
Aluminum Wire	--	15	20	30

No poor practices or code deviations were found.

4.5.11 Investigation Results - Step 10

The investigator was now ready to review the notes taken and evidence collected during the investigation.

1) The fire originated in or near the east wall electrical receptacle in bedroom no. 2.

2) The east wall electrical receptacle had the following damage:

a) Pitting under the binding screws (see figures 4.5.4-1 and 4.5.4-2);
b) pitting on the base plate (see figure 4.5.4-3);
c) burned hole in metal yoke (see figure 4.5.4-4).

3) Two adjacent wood studs in the east wall of bedroom no. 2 were deeply charred on their inside faces (within the stud cavity) with char on one stud commencing about ten inches from the floor.

4) The circuit breaker for the branch circuit serving bedroom no. 2 tripped at 0115 hours. (Clocks in bedroom nos. 1 and 2 stopped at 0115 hours.)

5) The fire department received the alarm at 0117 hours and arrived at the house at 0120 hours.

6) No problems were found in the panelboard.

7) The total current through the east wall receptacle in bedroom no. 2 prior to and during the fire was 9.0 amperes, and consisted of an electrical blanket, an electric heater and electric clock.

8) There was no prior history of electrical problems.

9) The workmanship on the electrical distribution system was satisfactory.

10) All circuits, including the branch circuit serving bedroom no. 2, had the properly sized circuit breakers for the wire gauges used.

4.5.12 Conclusions

Based on the evidence collected during the investigation, the following conclusions were developed by the investigator:

1) Heavy charring on the inside faces of the two adjacent wood studs in the east wall of bedroom no. 2 indicated that the fire began as a concealed fire within the wall and spread from this point into the room as well as into the attic.

2) The fire had been developing for some time prior to discovery by the occupants, probably as a slow heat buildup within the east wall receptacle. This conclusion was based on the fact that, when the fire department arrived, there was already extensive fire present in bedroom no. 2 and in the attic, although the fire department was on the scene only five minutes after the circuit breaker for bedroom no. 2 had opened. (Clocks stopped at 0115 hours, fire department arrival at 0120 hours.) The corollary conclusion is that the opening of the circuit breaker was due to the severe damage suffered by the east wall receptacle from fire exposure.

3) Before and during the fire, there was sufficient current flow (9.0 amperes) through the east wall receptacle in bedroom no. 2 to create a localized heating condition at the receptacle if one or more of the binding screws were loose.

4) The pitting on the base plate of the east wall receptacle, as well as on the underside of the binding screws of this same receptacle, indicated that arcing was taking place as the current passed through the receptacle. Such arcing is consistent with loose binding screws but is not a characteristic of external fire exposure.

5) The tripping of the circuit breaker serving the east wall receptacle in bedroom no. 2 was due to contact between the "hot" side base plate of the receptacle and the grounded yoke (see figure 4.5.4-3) after the plastic insulation/separation portion of the receptacle had been burned away by the exposure fire.

6) Therefore, the investigator concluded that:

a) The cause of the fire in the dwelling was electrical;
b) the fire originated in the east wall receptacle in bedroom no. 2;
c) the binding screws in the receptacle were loose resulting in a poor connection for the wires in the receptacle;
d) the downstream electrical load of 9.0 amperes, which passed through the east wall receptacle in bedroom no. 2, was sufficient to produce localized heating in the receptacle, and
e) over a period of time, the localized heating was sufficient to ignite the wood stud to which the receptacle was connected.

4.5.13 Summary

The above case study is an example of a systematic, step-by-step investigation of an electrical fire. While an electrical cause could have been assigned to this fire early in the investigation, based on the location of the electrical receptacle at the point of origin, the investigator continued the investigation until a complete and logical explanation had been developed to explain the generation of sufficient heat to initiate the fire. The circumstances of each electrical fire investigation will be different. However, the step-by-step procedure described in this case study generally will be applicable in any electrical fire investigation.

Not all fire investigators possess the expertise or have the resources available to do the in-depth study illustrated here. In such cases, the services of a competent electrical inspector, electrical engineer, or similar experts, may be necessary and should be obtained, if available.

4.6 EXPLOSIONS

4.6.1 Introduction

Occasionally, the fire investigator will be called upon to investigate explosions where no fire was involved. In such cases, the determination of the origin and cause of the explosion may be all that is necessary. More often, however, an explosion in a building will result in a secondary fire. In this case, the investigator may have difficulty in establishing the origin and cause of the explosion due to subsequent fire damage which may mask, if not destroy, clues relating to the explosion. And finally, a fire may result in an explosion which is only incidental to the fire. In this instance, the explosion effects may mislead the investigator or, at the least, hamper the investigator's efforts in determining the origin and cause of the original fire.

The purpose of this chapter is to give the fire investigator some understanding as to the types of explosions that may be encountered and the effects these explosions may produce, thus aiding the investigator in determining what happened. Some of the mechanisms, materials, and processes which can cause or contribute to an explosion will also be discussed.

4.6.2 Definition of an Explosion

There are many definitions of an explosion, some of which are very complicated. For purposes of this chapter, however, a good definition is: an explosion is a rapid release of energy which produces a pressure wave or shock wave in air, usually accompanied by a loud noise.

4.6.3 Types of Explosions

There are widely differing types of energy sources which can produce the pressure waves mentioned in chapter 4.6.2. Not all of these are fire related. Explosions can be divided, for purposes of description and understanding, into high-yield explosions and low-yield explosions. The difference between the two is the rate at which energy is released. Thus, those explosions with higher energy release rates will be high-yield explosions and vice versa. This distinction between the high-yield and low-yield is arbitrary, with some overlap. But this distinction will, for most cases, suffice for the purpose of understanding explosions and for conducting the subsequent investigations.

One characteristic difference, for identification purposes, between high-yield and low-yield explosions is the resulting damage effects. High-yield explosions tend to produce shattering of nearby materials and cratering of floors. Generally, this is accompanied by high-velocity projectiles and/or fragmentation. Low-yield explosions, on the other hand, do not normally produce this concentrated shattering. Their action is more of a pushing or shoving action.

The net destructive results of the two types of explosions can be similar, particularly when equivalent amounts of energy release are involved, although the damage effects in the immediate vicinity of the explosion may differ. For instance, detonating a stick of dynamite in a room (a high-yield explosion) might result in a hole in the floor (cratering), shattering of nearby furniture and blowing out of nearby windows, either by the pressure wave or from projectiles. The chance of a resulting fire is low. On the other hand, vaporization of an appropriate amount of gasoline with subsequent ignition (low-yield explosion) would produce no hole in the floor, nor would it result in shattering of nearby furniture. But it could result in ignition of combustible furniture and draperies, blowing out of the windows by the pressure wave and perhaps dislocation of the walls of the room as well, depending on their rigidity.

In the first example, a fire, if it resulted at all, would probably be from secondary ignition sources, such as dislodged electrical circuits possibly combined with a fuel source such as a broken gas pipe. In the second example, there is the possibility that the explosion itself could produce a fire, particularly if easily ignitable materials, such as combustible furniture and draperies, were present in the room and were enveloped in the burning fire gases produced by the explosion.

4.6.3.1 High-Yield Explosions

High-yield explosions generally include the following:

1) Commercial explosives, such as TNT, dynamite, nitroglycerin, ammonium nitrate, and the derivations and combinations thereof;

2) black powder and smokeless powder (when confined).

The fact that a commercial explosive has been involved will usually be self-evident from the damage, for example, extensive shattering or cratering. But, by far the more common accidental explosions encountered by fire investigators will be low-yield explosions involving flammable gases and liquids. For this reason, only low-yield will be discussed in detail. Further information on this subject can be found in the literature; an example is a book by Meidl (1)[1].

4.6.3.2 Low-Yield Explosions

Low-yield explosions generally include explosions or ruptures of the following:

1) Flammable liquids and gases;

2) combustible dusts;

3) pressure vessels;

4) black powder and smokeless powder (when unconfined).

One also could include back-draft or smoke explosions under this category as these produce symptoms resembling explosions, that is, loud noises, which may be described by witnesses as an explosion.

Pressure vessel ruptures are defined here as explosions, that is, rapid energy release accompanied by a loud noise. As these ruptures seldom produce fires and as their origin is usually self-evident, pressure vessel ruptures will not be covered in this handbook.

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[1]Figures in parentheses refer to references at the end of the chapter.

4.6.4 Flammable Liquids and Gases

Flammable liquids and gases possess four interdependent properties which determine whether an explosion can take place. The four properties are:

1) Flashpoint;

2) explosive limits*;

3) ignition temperature;

4) vapor density.

4.6.4.1 Flashpoint

Flammable liquids do not burn. Neither do flammable liquids explode. It is the vapor rising from the liquid surface which, when mixed with air, forms the explosive mixture. The commonly-used terms "flammable" and "combustible" are legal terms usually describing liquids with flashpoints below 100°F (flammable) and 100°F and above (combustible).** The 100°F (38°C) break point was chosen because it separated liquids which give off ignitable vapors at room temperatures from those which do not. For a variety of reasons, such as evaporation or formula changes, a liquid, which is nominally combustible may be, in fact, flammable. If there is doubt, samples should be obtained and tested in a laboratory specializing in determining flashpoint indexes (see references listed in chapter 5.3.8).

The temperature at which a liquid gives off sufficient vapors to form an ignitable mixture with air is termed the liquid's flashpoint. (See chapter 5.3.3 for a distinction between flashpoint and firepoint.) Both flammable and combustible liquids have flashpoints but, the flashpoints for combustible liquids will be 100°F (38°C) and above as noted earlier. In a fire these temperatures may be reached quite easily and under these conditions combustible liquids can and do form explosive vapor/air mixtures. The fire itself then acts as the ignition source for these vapor/air mixtures and explosions may result. Flashpoints for some of the more common flammable liquids are presented in table 4.6.4.2-1.

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*Also referred to as flammability limits; in this chapter, explosive limits will be used.

**Some regulations still use "inflammable" for "flammable". "Flammable" is the preferred word due to confusion as to the meaning of the prefix "in". In addition, the definition of "flammable" includes a requirement that the liquid have a vapor pressure not exceeding 40 psia at 100°F (38°C). In essence, all this requirement says is that those fluids with boiling points around room temperature and above will be defined as liquids and those with boiling points below room temperature will be defined as gases.

4.6.4.2 Explosive Limits

The range of mixtures of air with a flammable gas or vapor (from a liquid) that will burn (explode) is relatively narrow for most gases and vapors. Below a certain percentage, by volume, a mixture of flammable gas or vapor with air will be too lean (lacking sufficient fuel) to explode. Above a certain percentage, the mixture will be too rich to explode. The lower percentage and the upper percentage are called the explosive limits. For gasoline, as an example, the limits are approximately 1.3 percent to 6.0 percent. For natural gas, or methane, the limits are 5.0 to 15.0 percent. These limits only apply at normal temperature and atmospheric pressure. Explosive limits of some of the more common flammable liquids and gases are given in table 4.6.4.2-1.

Figure 4.6.4.2-1 represents, pictorially, the effects that variations of the gas-air mixture have on the explosive limits. Note that combustion is possible above the upper explosive limit. This combustion is typified by the gas burner on a gas cooking range.

4.6.4.3 Ignition Temperature

Before a flammable gas or vapor/air mixture can ignite, the mixture or at least a small portion of it, must be raised in temperature. The temperature necessary to produce the ignition is called the ignition temperature. (Also referred to as self-ignition, autoignition, and autogeneous ignition temperatures.) And while the mixture may occupy a large volume, if the total mixture lies within the explosive limits, a very small spark occurring anywhere within the mixture's volume can produce ignition of the total mixture. Table 4.6.4.2-1 includes approximate ignition temperatures for some of the more common flammable liquids and gases. (See chapter 5.3.3 for a discussion on the variability of ignition temperatures.)

4.6.4.4 Vapor Density

The vapor density of a flammable vapor or gas is usually measured relative to that of air. A substance with a vapor density of two, for instance, is twice as heavy as air. The vapor density and subsequent behavior of the vapor or gas discharged into the air can be extremely important. For instance, the vapors of a liquid which are heavier than air tend to sink to the lowest possible level. They can flow out over considerable distances while forming concentrations within the explosive limits. On the other hand, those which are lighter than air tend to rise and thus remove themselves from possible ignition sources at lower levels. What this means, on a more practical level, is that leaking propane gas is more likely to cause an explosion in the basement of a house, where ignition sources are low, than leaking natural gas. If the natural gas is confined, however, such as in a basement from which it cannot escape, and if the leak continues, then ultimately the basement will be filled from the ceiling to the floor with the gas. Should there

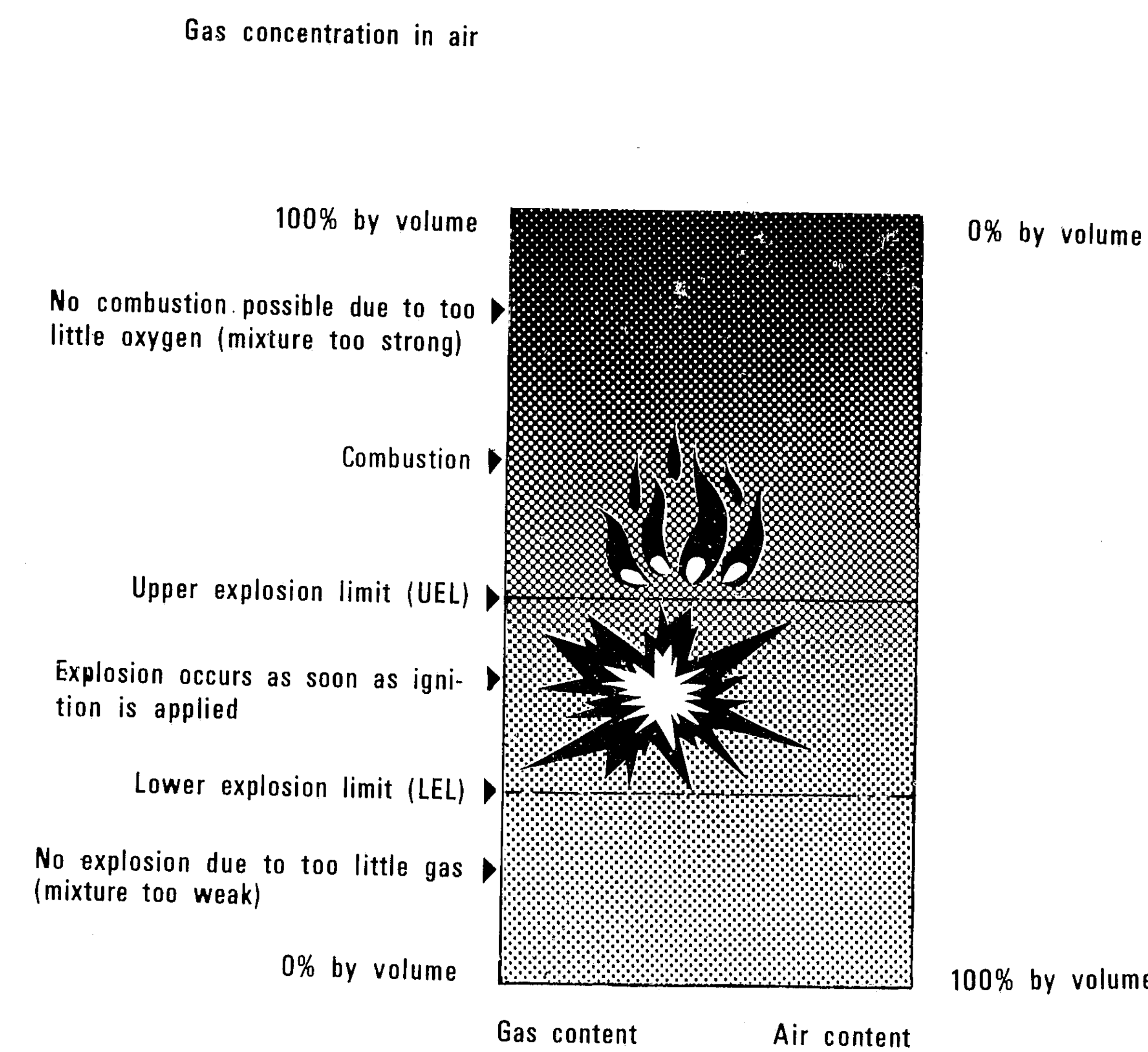

Figure 4.6.4.2-1

Table 4.6.4.2-1 Properties of selected flammable liquids and gases

Name	Flash point (°F)	Explosive limits (% by vol.) Lower	Upper	Ignition Temperature (°F)	Vapor Density (Air=1)
Acetone	0	2.6	13.0	869	2.0
Acetylene	Gas	2.5	100.0	581	0.9
Acrolein	-15	2.8	31.0	455	1.9
Acrylonitrile	32	3.0	17.0	898	1.8
Ammonia	Gas	15.0	28.0	1204	0.6
Amyl acetate (nor)	76	1.0	7.5	680	4.5
Amyl acetate (sec)	89	-	-	-	4.5
Benzene (Benzol)	12	1.3	7.1	1040	2.8
Benzine	(See Petroleum ether)				
Butadiene (1,3)	Gas	2.0	12.0	788	1.9
Butane (nor)	Gas	1.8	8.4	761	2.1
Butane (iso)	Gas	1.8	8.4	860	2.1
Butyl acetate (nor)	72	1.4	15.0	797	4.0
Butyl alcohol (nor)	84	1.4	18.2	650	2.6
Butyl alcohol (iso)	82	1.7	11.0	800	2.6
Butyl ether	(See Dibutyl ether)				
Carbon disulfide	-22	1.3	50.0	194	2.6
Carbon monoxide	Gas	12.5	74.0	1204	0.97
Cyclohexane	-4	1.3	7.8	473	2.9
Cyclopropane	Gas	2.4	10.4	932	1.5
Denatured Alcohol-95%	60	-	-	750	1.6
Dibutyl ether (nor)	77	1.5	7.6	382	4.5
Diethylene dioxide	54	2.0	22.0	509	3.0
Diethyl ether	-49	1.9	36.0	320	2.6
Dimethyl ether	Gas	3.4	27.0	662	1.6
Dioxane-p	(See diethylene dioxide)				
Divinyl ether	-22	1.7	27.0	680	2.4

Name	Flash point (°F)	Explosive limits (% by vol.) Lower	Upper	Ignition Temperature (°F)	Vapor Density (Air=1)
Ethane	Gas	3.0	12.5	959	1.0
Ether	(See Diethyl ether)				
Ethyl alcohol	55	3.5	19.0	689	1.6
Ethyl ether	(See Diethyl ether)				
Ethylene	Gas	2.7	36.0	914	1.0
Ethylene oxide	Gas	3.0	100.0	804	1.5
Formaldehyde	Gas	7.0	73.0	806	1.1
Gasoline (auto)	-50	1.3-1.4	6.0-7.6	700	3.0-4.0
Heptane (nor)	25	1.1	6.7	419	3.5
Heptane (iso)	<0	1.0	6.0	536	3.5
Hexane (nor)	-7	1.2	7.4	437	2.9
Hexane (iso)	-20	1.0	7.0	-	3.0
Hydrogen	Gas	4.0	75.0	752	0.1
Hydrogen sulfide	Gas	4.3	45.0	500	1.2
Isobutyl alcohol	(See Butyl alcohol-iso)				
Isobutane	(See Butane-iso)				
Isopentane	(See Pentane-iso)				
Isopropyl alcohol	(See Propyl alcohol-iso)				
Methane	Gas	5.0	15.0	1004	0.6
Methyl alcohol	54	6.7	36.0	725	1.1
Methyl ether	(See Dimethyl ether)				
Methyl ethyl ketone	28	1.9	10.0	960	2.5
Naptha, VM&P	20-45	0.9	6.0	450-500	3.8
Octane (nor)	56	1.0	3.0	428	3.9
Octane (iso)	10	1.0	6.0	784	3.9
Pentane (nor)	-57	1.4	7.8	500	2.5
Pentane (iso)	-60	1.4	7.6	788	2.5
Petroleum ether (Benzine)	0	1.1	5.9	550	2.5

Name	Flash point (°F)	Explosive limits (% by vol.) Lower	Upper	Ignition Temperature (°F)	Vapor Density (Air=1)
Propane	Gas	2.1	9.5	842	1.6
Propyl alcohol (nor)	59	2.1	13.5	824	2.1
Propyl alcohol (iso)	53	2.5	12.0	750	2.1
Propylene	Gas	2.4	11.0	860	1.5
Toluene	40	1.3	7.0	896	3.1
Vinyl acetate	18	2.6	13.4	800	3.0
Vinyl chloride	Gas	3.6	33.0	882	2.2
Vinyl ether	(See Divinyl ether)				
Xylene (meta)	77	1.1	7.0	986	3.7
Xylene (ortho)	63	1.0	6.0	869	3.7
Xylene (para)	77	1.1	7.0	986	3.7

Note: The data in the above table has been compiled primarily from Flammability Characteristics of Combustible Gases and Vapors by M. G. Zabetakis, U.S. Department of the Interior, Bureau of Mines Bulletin 627, Washington, DC, 1965, with some assistance from references (2) and (3). For materials not listed in the above table the reader should consult these references. Where a material is known only by its trade name, reference (4) may be of assistance in determining its flash point.

See chapters 4.6.4.1, 4.6.4.2, 4.6.4.3, 4.6.4.4, 5.3.2 and 5.3.3 for a discussion of the application of Table values.

be an ignition source near the floor, the resulting explosion may be more violent, due to the larger amount of gas present. Table 4.6.4.2-1 includes vapor densities for some of the more common liquids and gases.

4.6.5 Combustible Dusts

Combustible materials in solid form, when ignited, burn relatively slowly, releasing energy gradually. The rate of burning of the combustible material and the ease of ignition are, in general, dependent on the ratio of the surface area to volume of the material exposed to air. The larger the block of material, that is, the greater the volume to surface area, the more difficult it is to ignite and the slower it burns. On the other hand, as the combustible material is reduced in size, the easier it is to ignite and the more readily it burns. If the combustible material is reduced to a powder or dust and is intimately mixed with air through mechanical agitation or through blowing, the dust cloud, if ignited, can burn so rapidly an explosion is produced.

Combustible dusts include agricultural dusts, carbonaceous dusts, chemical dusts, metal dusts, pesticide dusts and dusts from plastics manufacturing. An extensive list of dusts can be found in reference (5). While there are literally hundreds of dusts capable of producing dust explosions, it is the agricultural dusts which have been responsible for the more spectacular and destructive explosions.

Combustible dusts, like flammable vapors and gases, have finite explosive limits. For most combustible dusts, the lower explosive limit is around 0.02 ounces suspended in one cubic foot of air. The upper explosive limit is not as well defined.

Again, as with flammable vapors and gases, combustible dusts must contact a source of ignition to be ignited. This ignition can be from a small spark, open flame, or hot surface. In the last case, many combustible dusts can be ignited by hot surfaces in the range of 750° to 1100°F (399° to 593°C). The factors then that determine whether a combustible dust cloud will explode are:

1) whether the concentration of the combustible dust cloud in air is above the lower explosive limit;

2) whether a source of heat is present which is above the ignition temperature of the dust cloud.

Dust explosions are not very common, if one compares these to flammable vapor/gas explosions. Dust explosions tend to be a hazard in certain types of occupancies. Such occupancies include grain elevators, flour mills, candy factories, paint manufacturing operations, metal powder operations, and similar occupancies. For this reason, the fact that a dust explosion may have occurred will be self-evident, if the type of occupancy is one of those cited above. But the investigator will still be faced with determining the cause and origin of the explosion.

Dust explosions produce damage effects similar to flammable gas/vapor explosions. That is, walls are dislodged or blown out and building collapse may be initiated. Combustible dust explosions have one peculiarity not present in flammable gas/vapor explosions. An initial dust explosion in, say a grain elevator, may be rather small in intensity. This first explosion may raise additional dust clouds producing a second explosion of higher intensity than the first explosion and so on, resulting in what amounts to a continuous chain of explosions. This chain of explosions may occur so quickly that the total process may seem to be only one, relatively long, explosion to witnesses. Obviously, if a chain of explosions occur, the investigation as to cause and origin becomes more complicated.

In the event of a chain of explosions, the origin sometimes can be located as the initial explosion generally produces partially burned combustion products and this residue can be found on any structure remaining at the point of origin.

Caution should be exercised by the investigator as often times a grain explosion will result in smoldering combustion in the stored grain products. This smoldering combustion may not be immediately noticeable and may pose a hazard to the fire investigator.

Further information on dust explosions can be found in the literature. An excellent text on dust explosions is reference (6).

4.6.6 Summary

Explosions may occur without a resulting fire, with a resulting fire, or because of a fire. Explosions may be high-yield such as that produced by commercial explosives, or low-yield such as that produced by vapors from flammable liquids, by flammable gases, or by combustible dusts. Low-yield explosions also may occur from the rupture of pressure vessels. In addition, back-draft or smoke explosions may produce explosive-like effects and be so reported by witnesses. It should be noted, however, that back-draft explosions are always the result of an initiating fire and not the other way around.

High-yield explosions will be characterized by shattering and cratering with the production of projectiles as well. Fire does not always result from high-yield explosions. Low-yield explosions will be characterized by slower-moving, pressure waves which push and shove walls around but without the shattering and cratering of high-yield explosions. Secondary fires are more likely to result from low-yield explosions.

The pressure developed by high-yield or low-yield explosions may cause walls and partitions to be dislodged. Whether these walls and partitions were dislodged at the top or bottom does not necessarily indicate the type of explosion nor the material exploding but only that the pressure created by the explosion attacked the weakest point of the structure.

Combustible dust explosions are low-yield explosions producing similar effects to other types of low-yield explosions. Combustible dust explosions, however, tend to be confined to certain types of industrial processes known for their relative frequency of this type of explosion.

4.6.7 References

(1) Meidl, James H., Explosive and Toxic Hazardous Materials. Beverly Hills, CA, Glencoe Press, 1970.

(2) Handbook of Industrial Loss Prevention. 2nd edition. New York, McGraw-Hill Book Company, 1967.

(3) Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solids. NFPA 325M. Boston, National Fire Protection Assoc., 1969.

(4) Flash Point Index of Trade Name Liquids. NFPA 325A. Boston, National Fire Protection Assoc., 1972.

(5) Fire Protection Handbook, 14th edition. Boston, National Fire Protection Assoc., 1976, Table 3-8A, p. 3-107.

(6) Palmer, K. N., Dust Explosions and Fires. New York, Halstead Press, 1973.

5. Chemistry and Physics of Fire

5.1 FRIENDLY AND UNFRIENDLY FIRES

Combustion may be defined as a chemical and physical reaction between a fuel and oxygen from the air which generates heat. Combustion usually produces light, smoke, and combustion gases as well. Controlled combustion, or friendly fires, has been of enormous benefit to mankind but when uncontrolled can be a terribly destructive force. Many destructive, or unfriendly fires, grow out of controlled, useful combustion.

5.2 FUEL, OXYGEN, IGNITION SOURCE

Three conditions are necessary to have a fire: a fuel must be present; it must be in contact with oxygen (usually from the air), and there must be a source of energy to raise the temperature of the fuel and oxygen to a point where they react rapidly (ignite). Fuels and oxygen coexist safely everywhere in nature. As an example, gasoline, which forms a highly flammable mixture in air, is handled safely in enormous quantities every day in the United States. Only when an ignition source, such as a spark, heat or flame, is present can a fire result.

5.3 CHEMISTRY OF FIRE

5.3.1 Introduction

Fuels may be classified as gases, liquids, or solids. Each behaves differently in fires. Most fuels are organic in nature; that is, they are made up of carbon and hydrogen. They may be natural products such as coal, oil, or plant materials. Or, they may be products derived from these sources, such as coke, gasoline, lumber, paper, or the wide range of chemicals and plastics produced by industry.

When organic fuels burn with an abundant supply of air the principal products are carbon dioxide and water vapor.

Nitrogen-containing plastics, such as nylon, produce nitrogen gas among the products of combustion in addition to carbon dioxide and water vapor. Similarly, plastics containing chlorine, such as polyvinyl chloride, produce hydrogen chloride, an acid gas, when they burn along with the carbon dioxide and water.

When combustion takes place in a limited air supply, as is the case in building fires, combustion will be incomplete. Incomplete combustion produces toxic gases such as carbon monoxide and hydrogen cyanide (from nitrogen-containing materials), along with other irritating and toxic gases and smoke particles.

In burning buildings incomplete combustion is the rule, with a large variety and quantity of toxic, flammable, even explosive, gases being generated. Overall, then, there is no "perfect combustion" in a building fire.

5.3.2 Gaseous Fuels

Fuel gases, such as natural gas, since they mix readily with air, present a very serious fire hazard. They are readily ignited by a very small ignition source, such as a spark. As they flow freely, they can reach remote ignition sources. Once ignited, the flame spreads rapidly through the fuel/air mixture, generating high temperatures, igniting other combustibles, and creating a destructive pressure wave (explosion).

Fuel gas/air mixtures will burn only if their composition lies within certain limits. If the fuel concentration is too low (below the lower or lean limit, and often called the lower explosive limit, L.E.L.) insufficient fuel is present to sustain the flame. If the fuel concentration is too great (the upper or rich limit and often called the upper explosive limit, U.E.L.) not enough oxygen is present in the mixture for combustion. The region between the upper and lower limits is called the flammable range. From a fire safety standpoint, generally it is only the lower limit that is of practical interest since a mixture above the upper limit will always have to pass through the flammable range to bring the mixture to within safe limits. Flammability limits for typical gaseous fuels are given in table 4.6.4.2-1.

5.3.3 Liquid Fuels

When the surface of a combustible or flammable liquid is exposed to the air, some of it converts to a vapor and mixes with the air. In a closed container the concentration of vapor in the air reaches an equilibrium value (the saturated vapor pressure), which depends on the composition of the liquid and the temperature. The vapor pressure of a liquid increases with increases in temperature until, at the boiling point of the liquid, the vapor pressure is just equal to atmospheric pressure and rapid vaporization (boiling) occurs.

The combustion of a liquid actually takes place in this fuel/air mixture above the liquid surface rather than at the surface of the liquid. In this respect, it resembles the combustion of a gaseous fuel. For ignition to take place, the concentration of fuel vapor in air must exceed the lower flammability limit; that is, the temperature of the liquid must be high enough for the equilibrium vapor concentration to be within the flammable range.

The minimum temperature at which vaporization is sufficient to produce a flammable liquid fuel/air mixture is called the flash point of the liquid. It is measured by gradually heating a sample of the liquid in contact with the air and periodically bringing a small ignition flame near the surface (1)[1]. The minimum temperature at which a flash of flame spreads over the surface is recorded as the flash point. It is one of the most important properties in determining the fire hazard of a liquid. Flash points of typical liquid fuels are listed in table 4.6.4.2-1.

The initial flash seen when the ignition source is brought near to the liquid surface may consume the fuel in the fuel/air mixture and the flash will die out. At a slightly higher temperature, vaporization of the liquid is sufficient to sustain the flame. This temperature at which the sustained flame is observed is called the fire point. The flash point is more widely used than the fire point to characterize the flammability properties of a liquid.

A liquid fuel is not readily ignited by a small ignition source if the liquid's temperatures is below its flash point, but it can be ignited by a larger ignition source which is capable of heating the surface of the liquid to the flash point. Once ignited, radiation from the fire will increase the temperature of the liquid, increasing the rate of vaporization and the intensity of the fire.

Liquid sprays and mists (for example, from a leak under pressure) are more easily ignited and burn more vigorously than the bulk liquid because of the larger surface area per unit volume in contact with air. An example of this is the pressurized oil burner of an oil-fired heating plant.

Another measured property of liquid fuels is ignition temperature, also referred to as autoignition temperature. The ignition temperature of a liquid fuel is that temperature to which the fuel, in air, must be heated to ignite spontaneously. The ignition temperature of a specific substance can vary widely depending upon many conditions. The following information is quoted from reference (2):

[1]Figures in parentheses refer to references at the end of the chapter.

"Ignition temperatures observed under one set of conditions may be changed substantially by a change of conditions. For this reason, ignition temperatures should be looked upon only as approximations. Some of the variables known to affect ignition temperatures of flammable liquids and gases are percentage composition of the vapor or gas-air mixture, shape and size of the space where the ignition occurs, rate and duration of heating, kind and temperature of the ignition source, catalytic or other effect of materials that may be present, and oxygen concentration. As there are many differences in ignition temperature test methods, such as in size and shape of containers, method of heating and ignition source, it is not surprising that different ignition temperatures are reported for the same substance by different laboratories.

As illustration of the effects of test methods, the ignition temperatures of hexane determined by three different methods were 437°F, 637°F, and 950°F, respectively. The effect of percentage composition is shown by the following ignition temperatures for pentane: 1,018.4°F for 1.5 per cent pentane in air, 935.6°F for 3.75 per cent pentane, and 888.8°F for 7.65 per cent pentane. The following ignition temperatures for carbon disulfide demonstrate the effect of size of space containing the ignitible mixture: in a 200 ml (milliliter) flask the ignition temperature was 248°F; in a 1,000 ml flask 230°F; and in a 10,000 ml flask 205°F. That materials of the container walls in which the flammable mixture is in contact may affect the ignition temperature is illustrated by ignition temperature determinations for benzene conducted in various containers: 1,060°F in a quartz container, 1,252°F in iron, and 1,330°F in zinc."

These variations in ignition temperatures for a given liquid fuel should be kept in mind by the investigator should he encounter a fire where ignition of a liquid fuel by an external heat source is thought to be involved.

Flash points are used to provide for legal regulation of liquid fuels. Liquids with flash points below 100°F (38°C) are classified as "flammable" under most codes, while those with flash points above 100°F (38°C) are classified as "combustible". Regulations for the handling and storage of "combustible" liquids, for instance, are more lenient than for "flammable" liquids. There is much misunderstanding of these terms. People accustomed to obtaining information from handbooks and tables, often take the published figures as physical constants, which they are not. They are merely observed phenomena and are truly valid only for the sample tested in the apparatus in which tested.

Floor wax, nominally "combustible", ignited from the spark of a floor resulting in a large fire. Tests of a similar material gave an actual flash point of 74°F (23°C). A flammable liquid mixture, such as alcohol and water, may or may not ignite under ordinary temperatures depending upon the percentage (or proof) of alcohol. Whiskey will ignite; wine will not. However, if the wine is heated, it will ignite. The relationship between the fire point and proof of various alcoholic beverages is shown in table 5.3.3-1.

Table 5.3.3-1 Fire Points[1] for Various Alcoholic Beverages

Beverage	Fire Point °F	Fire Point °C
Whiskey		
80 proof[2]	100	38
100 proof	95	35
Gins		
80 proof	100	38
95 proof	98	37
Rums		
80 proof	100	38
140 proof	80	27
Brandies		
80 proof	100	38
140 proof	80	27
Wines		
20 proof (10%)	above 180	83
40 proof (20%)	135	57

Source: Handbook of Industrial Loss Prevention. 2d ed. New York, McGraw-Hill Company, 1967, p. 60-1.

[1]Fire points typically are only a few degrees higher than flashpoint.
[2]For alcohol percentage, divide proof by two.

Published characteristics of flammable liquids must be used with caution in attempting to determine what part a particular flammable liquid played in the development of a fire.

5.3.4 Solid Fuels

The combustion of solid fuels is more complex than the combustion of a liquid or gas. For example, as wood is heated certain gases are given off. The wood is decomposing even though flaming has not yet developed. The reaction moves from the surface into the wood. Gas continues to evolve. The wood is still absorbing heat (endothermic reaction). When enough gas is emitted (temperatures of about 600° to 900°F or 316° to 482°C are required), the gas ignites. The wood is now burning and contributing heat to the fire (exothermic reaction).

Surface area is important in the burning of solids. Materials with large surface-to-volume ratios, such as paper or wood shavings, are readily ignited by a match while a solid block of wood may be difficult to ignite. As plywood and plywood paneling burn, the plywood layers separate increasing the surface area. The total amount of fuel is not increased, but increasing the surface area increases the rate of burning.

For a long time it was thought that the damage to structural elements would be equal in fires where the total amount of heat generated was equal. More recent work indicates that short, hot fires may be more destructive to some materials than long, cooler fires, even though the total amount of heat given off is the same.

Many solid fuels, particularly plastics, will volatilize and burn almost completely when subjected to high temperatures. Other materials, particularly those made from wood, may be only partially volatilized and leave behind a carbon-rich char. The carbon is non-volatile but it will react with oxygen which diffuses to the solid surface, giving off a large amount of heat and causing the solid surface to glow brightly (glowing combustion). The glowing combustion of charcoal is an example. This is a relatively slow process and may continue for a long time after the more volatile flame-producing gases are used up.

Because of the low volatility of most solid fuels, flame spread over surfaces in the downward direction is relatively slow. Flame spread in the upward direction, where the fuel is heated by the rising flaming gases, is much more rapid. Flame spread in the horizontal direction falls between these two extremes. The flame spread, however, may be influenced by a variety of other factors, for example, reradiation from nearby surfaces or air flows.

5.3.5 Oxygen Requirements for Combustion

Since oxygen combines with fuel in the combustion process, the size of a fire may be limited by either the amount of fuel available or by the amount of oxygen which can reach the fire.

Oxygen will usually be supplied to the fire from the surrounding air. Air normally contains 20.9 percent of oxygen by volume or 23.2 percent by weight. The remainder (79.1%) consists of nitrogen and traces of other gases. Nitrogen is not consumed in the combustion process. One cubic foot of air contains 0.0175 lbs of oxygen (0.28 kg/m^3). The amount of oxygen required to burn a fuel will depend on the nature of the fuel. Hydrocarbons, such as gasoline, have the highest oxygen requirement, needing approximately 3.5 lbs of oxygen per pound of fuel or 200 cubic feet of air per pound of fuel. Paper has a much lower oxygen requirement, needing approximately 1.2 lbs of oxygen per pound of fuel or 69 cubic feet of air per pound of fuel. Most other common fuels will have oxygen requirements between these limits.

As an example of what this means, consider a fire started in a pile of paper in a closed room 10 by 10 by 8 ft (3.2 x 3.2 x 2.5 m). The 800 cubic-foot-room will initially contain about 14 lb (30.8 kg) of oxygen, sufficient to burn less than 12 lb (26.4 kg) of paper. The actual amount of fuel consumed, however, would be less since the fire will go out when the oxygen concentration drops to around 8 or 10 percent. The rest of the oxygen would remain unconsumed.

Thus, a fire in a tightly-closed compartment will go out due to lack of sufficient oxygen and will not grow to a dangerous size. Most fires, however, will have access to an unlimited air supply through open doors, windows and other openings. In such circumstances the fire will continue to burn until all of the fuel is consumed, unless the fire is extinguished.

5.3.6 Heats of Combustion and Maximum Flame Temperatures

The complete combustion of a pound (or gram) of a specific fuel yields a fixed quantity of heat. This quantity is known as the heat of combustion and will differ for different fuels. Among the common fuels, hydrocarbons (such as gasoline) have the higher heats of combustion while oxygen-containing fuels such as paper (cellulose) have lower values. Heats of combustion for typical fuels are listed in table 5.3.6-1.

The heat given off in a fire goes first to heat the gases coming off and then the nitrogen and any excess oxygen in the air. When the supply of oxygen is exactly sufficient to consume the fuel present, the flame temperature will be at a maximum. Maximum flame temperatures for typical fuels are listed in table 5.3.6-2. If the air supply is insufficient to burn the fuel completely, not all of the heat available will be released and the flame temperature will be reduced. If an excess of air is present, part of the heat will go to heat this excess air and again the flame temperature will be reduced.

The maximum flame temperature is probably never reached in a fire. Usually, the temperature will be much less due to mixing of the cooler surrounding air with the flame gases, incomplete combustion, and the loss of heat through windows and doors as well as to walls, ceilings, floors and room contents.

Table 5.3.6-1 Approximate heats of combustion of typical fuels

Fuel	Heat of Combustion kcal/g	Heat of Combustion Btu/lb
Methyl Alcohol	5.3	9,600
Ethyl Alcohol	7.1	12,800
Isopropyl Alcohol	7.9	14,200
Ethylene Glycol	4.5	8,100
Octane	11.4	20,500
Benzene	10.0	18,000
Gasoline	11.5	20,700
Kerosine	11.0	19,800
Fuel Oil	10.5	18,900
Crude Oil	10.8	19,500
Rubber	10.8	19,500
Wood	4.2 - 5.0	7,600 - 9,000
Paper	4.5	8,100
Polyethylene	11.1	20,000
Polystyrene	9.9	17,800
Polyurethane	6.2	11,200
Polyvinyl Chloride	4.0	7,200

Table 5.3.6-2 Maximum flame temperatures of typical gaseous fuels in air

Fuel	Flame Temperature °F	Flame Temperature °C
Methane (natural gas)	3400	1871
Propane (LPG)	3500	1927
Octane (gasoline)	4050	2232
Acetylene	4350	2399
Hydrogen	3700	2038
Benzene	4150	2288

5.3.7 Products of Combustion

The products of combustion from a hostile fire are as great a threat to humans as is direct exposure to the fire. The combustion products from all fires are toxic; the level of toxicity will depend on the concentration, the type of fuel, and the specific conditions of the fire. In a hot fire with a good air supply, the principal products will be carbon dioxide and water vapor. Carbon dioxide is mildly toxic while water vapor is not. The low oxygen content of the fire gases, due to the consumption of the oxygen in the fire, may make them dangerous, even in the absence of significant quantities of toxic gases. Around a free-burning fire, however, material being heated is generating quantities of toxic and combustible gases. Carbon dioxide in fires is always accompanied by some carbon monoxide. The ratio of carbon monoxide to carbon dioxide increases as the oxygen supply is decreased. Carbon monoxide is highly toxic and is the direct cause of a majority of fire deaths. A concentration of 3,000 ppm (parts per million) can cause death in half an hour while higher concentrations will cause correspondingly more rapid death.

When the supply of air to a fire is limited, combustion will be incomplete and, in addition to carbon monoxide, large quantities of other combustion products, including hydrocarbons and soot particles, will be produced. This mixture of products will contain insufficient oxygen for further combustion but can accumulate in a building. When additional oxygen (air) is introduced (if the window breaks or the door opens), rapid combustion can occur. A sudden and dangerous pressure rise, called the back-draft, is created. The back-draft resulting from the rapid combustion may be reported as an explosion by witnesses to the fire. (However, the investigator should be aware that there are other sources of explosions in fires, such as aerosol cans, which may mislead witnesses.)

Incomplete combustion also produces a variety of toxic and irritating gases, in addition to carbon monoxide. Nitrogen-containing materials such as wool, nylon and polyurethane, can produce highly toxic hydrogen cyanide and nitrogen oxides. Sulfur-containing materials, such as wool and rubber, produce sulfur dioxide. Chlorine-containing materials, such as polyvinyl chloride, produce hydrogen chloride, a choking, irritating gas. When dissolved in water, hydrogen chloride forms hydrochloric acid, a corrosive liquid which attacks metal surfaces. All fuels can produce aldehydes such as formaldehyde and acrolein. These are strong irritants which attack the lungs and may produce delayed respiratory complications. Toxic gases may remain at the scene of a fire after the fire has been extinguished. For this reason, breathing apparatus should be used in examining the site until it has been thoroughly ventilated. Ventilation may not, however, thoroughly clear cellars, basements and other low points. (The investigator should keep this in mind.) Fire gases may cause incapacitation of the victim before death occurs. In such cases escape is prevented and death may follow due to continued toxic gas exposure or burns from contact with the fire.

Smoke is the visible product of a fire. It consists of soot particles, partially burned fuel fragments and liquid droplets. The visible smoke serves as a warning of the presence of toxic gases, and the smoke particles themselves may contain toxic and irritating substances.

5.3.8 References

(1) Methods for measuring the flash points of various liquids can be found in the most recent edition of the following ASTM standards:

D 56 Flash Point by TAG Closed Tester
D 92 Flash and Fire Points by Cleveland Open Cup
D 93 Flash Point by Pensky-Martens Closed Tester
D 1310 Flash Point by TAG Open-Cup Apparatus

Annual Book of ASTM Standards, Part 23. Philadelphia, American Society for Testing and Materials, 1979.

(2) Fire Protection Handbook. 13th edition. Boston, National Fire Protection Assoc., 1969, p. 4-7.

5.4 HEAT TRANSFER IN FIRES

5.4.1 Introduction

Heat energy generated by a fire first heats the fire gases (flames) to a high temperature. It must then be transferred to other materials to spread the fire. This energy transfer can take place through convection, conduction and radiation, either singly or in combination.

5.4.2 Convective Heat Transfer

Convective heat transfer is the movement of the hot fire gases upwards and away from the fire source. Heat flows from regions of high temperature to regions of lower temperature. The rate of flow is proportional to the temperature difference between the two regions. As these gases come in contact with solid surfaces, such as walls, ceilings and building contents, heat energy is transferred to these surfaces and the gases are cooled in turn. Since the hot gases tend to rise, the ceiling and upper walls of a room will be heated first and most strongly. The flow of convective energy will follow the flow of fire gases, the temperature decreasing with distance from the fire source.

5.4.3 Conductive Heat Transfer

When a solid surface is heated by contact with hot gases, heat is carried from the surface into the interior of the solid by conduction. The conductivities of materials vary widely. Metals have high thermal conductivities (conduct heat readily), followed by other dense materials such as masonry. Porous and lightweight materials, such as wood and particle board, have still lower thermal conductivities while insulating materials, such as mineral wool or foam plastic, have very low thermal conductivities. The amount of heat absorbed by a wall, and thus the amount of cooling of the fire gases, will be greater for materials with high thermal conductivity. On the other hand, the surface temperatures of materials with low thermal conductivity or materials backed by insulation, such as a carpet with a pad, will rise more rapidly since the heat cannot be conducted rapidly from the surface to the interior. This may result in more rapid fire spread over the surface of these materials, providing they are combustible.

The rate of heat transfer to an object immersed in a flame will decrease as the temperature of the object increases until, as its temperature approaches that of the flame, the rate decreases to zero. Thus the temperature of any object in the fire can never exceed that of the flame heat source.

5.4.4 Radiant Heat Transfer

Radiant heat transfer takes place without direct contact between the heat source and the receiving surface. The transfer takes place by electromagnetic radiation or waves. Radiant heat transfer follows line-of-sight and does not turn corners. The warming of the earth's surface by the rays of the sun is one example of radiant heat transfer.

The quantity of heat transferred per unit of time by convection and conduction is approximately proportional to the difference in temperature between the heat source and the receiving surface. As a consequence, small changes in the temperature differential produce small changes in the rate of heat transferred. However, in radiant heat transfer, small changes in the temperature differential between the heat source and the receiving surface can produce large effects due to the nature of the laws of electromagnetic radiation which govern radiant heat transfer. This explains the danger from overheated stoves and heaters, particularly the black-colored, radiant-style, wood stoves currently in vogue. Clearances from combustibles that were more than adequate when fuel is burned at a low rate, rapidly become inadequate when fuel is burned at a high rate.

As in convective and conductive heat transfer, objects cannot be heated in a fire by radiation to a temperature higher than that of the flame source.

The amount of heat radiated also is a function of the area of the radiating surface. A small fire will have a relatively small radiant output. But as the fire grows, the radiation will increase. In addition, the upper part of the room will fill with a layer of hot, radiating smoke and gas, and the walls and ceiling surfaces will become heated and contribute further to the radiant energy falling on the floor

and other objects in the room. Temperatures of easily-ignited materials (such as paper or fabrics) may reach the point where they burst into flame without direct contact with the fire due to this radiant heat transfer. Thus, radiation can play a very important role in the spread of a fire. Figure 5.4.4-1 depicts the effect of radiation from the hot gas layer at the ceiling on the floor and other objects in the room.

Radiation also heats the burning fuel surface, increasing the rate of burning and the intensity of the fire. Radiation from the ceiling, ahead of the fire, is important in the spread of fire along carpeting in corridors. Differences in ceiling height, however, may cause significant differences in the flame spread on identical carpets, with the radiation from lower ceilings being more pronounced than that from higher ceilings. Similarly, it is thought that one of the causes for rapid flame spread in mobile homes is the relatively short distances between vertical surfaces, which promotes high levels of radiation and reradiation.

5.4.5 Other Methods of Fire Extension

Radiation, conduction, and convection are the classic methods of heat transfer and have long been cited as the methods of fire extension. This overlooks another important method of fire extension "Moving Flaming or Heated Material".

Burning shingles, when carried by the up-draft of the fire, have long been recognized as a potential method of fire extension (1)[1]. What is not often recognized is that the same phenomenon can occur inside of a building. Take, as an example, an office where papers are scattered around on the tops of desks, file cabinets and tables. In the event of a fire in this room, burning papers are likely to be lifted by the hot plume of the fire and deposited in different locations around the room. If the fire department arrives at this point, they may conclude that there were several different fires instead of just one and suspect that the fires were incendiary. It is appropriate, therefore, for the investigator to consider what types of materials were involved in the fire and their likely behavior under fire conditions in the process of determining the fire cause and origin.

Heat transfer also can result in secondary fires, fires away from the original point of origin. This can mislead if the investigator is not aware of this phenomenon. For example, consider a chair burning in a living room. As the chair burns, the room begins to fill with hot gases from the ceiling down. There are cloth draperies on windows and these draperies extend up close to the ceiling, into the hot gas layer. Before the room flashes over, the top of the draperies ignite, burn free of the drapery rods, and fall in a burning pile onto a sofa. Assume a few minutes later, the fire department arrives and extinguishes the

[1] Figures in parentheses refer to references at the end of the chapter.

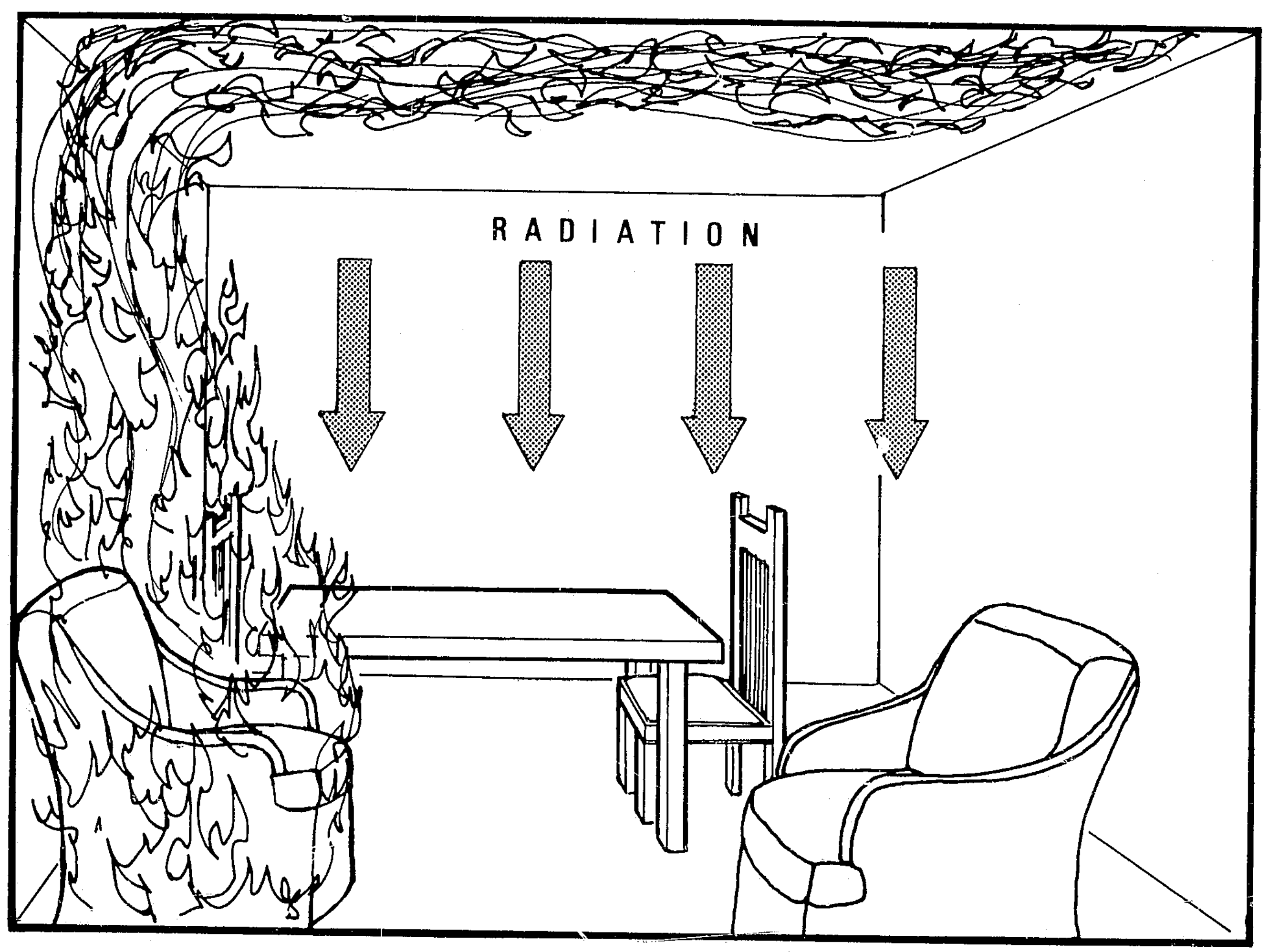

Figure 5.4.4-1

fire. In a casual examination of the room, the investigator might conclude that there were two fires, independent of each other, and suspect a malicious intent when such was not the case.

While fire usually moves upward, fire can fall down through hollow walls and cause confusion as to the point of origin. Many fires have been started by heated metal falling from cutting torches, falling, in some cases, several stories.

5.4.6 References

(1) Wilson, R. Los Angeles, Conflagration of 1961: The Devil Wind and Wood Shingles. NFPA Quarterly, Vol. 55, No. 9, pp. 242-288, January 1962.

5.5 FIRE DEVELOPMENT

5.5.1 Introduction

The severity and duration of a fire, as well as the hazard involved and the extent of damage, will depend on many elements. The nature of the ignition source, the proximity, type, and amount of fuel present (whether there is sufficient air available to sustain the burning), are just a few of the elements determining the behavior of the fire. In spite of the seemingly endless number of variations of elements which will affect the outcome of the fire, there exist several general characteristics common to most fires, a knowledge of which will aid the fire investigator in understanding fire development.

5.5.2 Ignition

The nature of the ignition source, combined with the first fuel item involved, will determine the initial fire development. For example, one extreme might be an explosion and the resulting fire from operating an electrical switch in a room filled with a natural gas/air mixture caused by a leaking gas main. At the other extreme might be a piece of combustible material located close to a furnace or stove flue. Upon being heated over weeks, months or years, the material could begin to smolder and finally burst into flame.* The ignition source for most fires would generally fall between these extremes. A cigarette dropped into the folds of an upholstered chair or bedding could cause the chair or bedding to smolder for several hours before one might observe a flame. A pan of cooking oil being heated and left unattended on a kitchen stove could ignite in a matter of minutes.

The intensity or strength of the ignition source in reference to fuel is important. A light switch is generally not thought of as an ignition source nor would a cigarette placed on a plank of ordinary lumber be considered dangerous. Yet by switching to a gas, liquid, dust or easily ignitable plastic, ignition can and does take place from quite weak ignition sources. For example, flaming ignition (the direct contact of a flame with the material or fuel), is potentially dangerous for any fuel. The temperature of an open flame, be it a match, candle, torch, fireplace, furnace, or kitchen stove, is generally higher than other sources. Obviously the larger the flame the more the heat transfer and the greater the risk of ignition.

Simple theories of ignition require only that the material reach a certain critical temperature for ignition to take place. The item can be heated indirectly (for example, with a heater) until it reaches a high enough temperature and bursts into flame (autoignition). Or, the item can be heated directly with an open flame (piloted ignition). The material is raised to the required temperature and ignited by the flame. (Autoignition generally requires higher temperatures than piloted ignition.) The two processes, indirect or direct heating, are identical. The presence of the flame simply is faster in initiating the chemical chain reactions in the combustible gases (flaming) given off by the material at these high temperatures.

In reality, ignition is a more complex process than that described above. However, the concept of raising the temperature to high enough values is an easy one to understand and provides a simple means of ranking ignition sources as to their strength. An electric spark will produce extremely high temperatures but generally only for a very short time and only in a small volume. If there is a flammable mixture surrounding the spark, then there will be an explosion. At the other extreme is heating due to spontaneous ignition, mild frictional heating, and other lower temperature heat sources.

5.5.3 Flame Spread

Whatever was ignited, the next phase of the fire involves flame spread. The growth of the fire will involve both flame spread along the ignited or initial item, as well as from one item to the next. In the beginning stages of flame spread, the fire usually will be small and growing. The important elements again will be the material properties as well as the item's location. Generally, sufficient air is available in the initial stages of flame spread.

Heat transfer from the flame will raise the temperature of the unburned fuel adjacent to it causing the area of involvement to increase. As the area increases, the flames will become larger, resulting in larger heat transfer rates and larger areas of involvement. If conditions are favorable, a self-sustaining chain reaction occurs. How rapidly this takes place will change from material to material. A flame

will spread across the surface of gasoline in seconds. On the other hand, a flame will not spread across an oak floor and the chain reaction will stop, unless heat is supplied from some other nearby fuel. Carpeting may react like the oak floor, like gasoline, or somewhere in between, depending on the carpet material, the presence of padding, if any, the radiation from the ceiling, and the energy of the ignition source.

Heat loss from the material is also important in flame spread. If underlayment (pad) is placed under the carpet, increasing the thermal insulation between the carpet and the floor, the flame spread rate will increase since less energy would be lost from the burning area. This is the reason it is much easier to keep two or more logs alight in a fireplace since the radiant energy given off by the logs will be "captured" by the others and not lost to the surroundings as in the case of a single log.

Location is extremely important. The results of a small waste basket fire, located at the base of a combustible wall or at the edge of a bed or sofa, will be vastly different than the same waste basket fire placed in the center of the room. In general, upward flame spread rates will be significantly higher than horizontal or downward flame spread rates due to the heating by the hot combustion products flowing upward over the unburned fuel. The more closely spaced the items or fuel elements are in a given region, the higher the potential for fire spread from one item to the next. The further a nonburning item is from a burning one, the larger the flame must be before the nonburning item will ignite.

Flame spread tests are available to rank materials as to their potential hazard, that is, how easily flame will propagate along a given sample of the item when one end is lighted. They are described in reference (1).[1]

5.5.4 Effect of Enclosure

After the fire is started, the fire development will be determined by the room or building or, simply, the enclosure. Up until this point nothing has been said about where the fire is taking place, only that there was sufficient air available. From this point onward, fire development will be dominated by the effects of the room, building, or the enclosure.

Consider a lighted candle safely placed on a table in a room. The candle will burn continuously until it runs out of wax. It will not change conditions in the room and it will not be changed by the room. The amount of oxygen used up in the room will be made up by normal air infiltration and similarly, the combustion products will leave the room through leaks. Any heating effects in nearby items will be small.

[1]Figures in parentheses refer to references at the end of the chapter.

For a larger fire, however, the effect of the enclosure will begin to be felt. There are two primary effects that will now determine the course of the fire; one is ventilation, the other is called reradiation. The fire, beyond the size of a candle, will be consuming oxygen at a much greater rate, such that normal leaks will not be sufficient. For a completely sealed room the fire will go out due to a lack of oxygen.

Doors are not always closed or even present in open-plan homes or offices. Hence, a ready supply of air is generally available to a fire and the fire will grow. Fresh air will be drawn in through the lower part of the door opening at the same time hot gases from the fire will be collecting at the ceiling, filling the upper portion of the room and spilling out under the top of the door frame. (In older buildings, transoms were often installed over doorways for ventilation and light. This permitted the room fire to spread quickly to the corridor. After several hotel fires in which transoms were a factor in fire spread (2,3), many codes were changed to require the permanent closure of the transoms, and they are not installed in modern buildings.)

The second effect of the enclosure will begin to be realized. The trapped hot gases in the upper portion of the room will heat the ceiling and walls. These surfaces, together with the gases themselves, will radiate down onto the unburned fuel in the room raising the fuel to the required temperature necessary for burning. An additional acceleration process (reradiation) now will be operating making the fire spread and grow further (see figure 5.4.4-1).

The larger fire will draw more and more air through the doorway. If the opening is large enough relative to the potential fuel supply, the controlling mechanism for further development is the amount of fuel present, the so-called fuel-controlled or fuel-limited fire. The fire will continue to grow until all of the fuel elements are burning inside the enclosure as long as there is more than an adequate supply of air coming through the door. This fire will continue in a more or less steady manner until the fuel is consumed.

5.5.5 Flashover

Consider the same sized opening, with considerably more fuel than in the previous case. The fire would continue to get larger, drawing more and more air, burning more and more vigorously. Temperatures and corresponding radiation feedback would rise until rather dramatically a phenomenon known as "flashover" occurs. Items in the room not in direct contact with the original flames suddenly burst into flame due to the high radiation levels. The rate of burning for all items in the room becomes so high that the amount of air coming through the door is inadequate. Flame lengths become longer and reach out through the door in search of more air to burn the additional combustibles and the "inferno" inside becomes controlled by the amount of air entering. This

is called a ventilation-controlled fire. The fire cannot get any larger in the room because all the air entering is being utilized. The fire will continue in this fashion until all the fuel is burned up.

Flashover can be abrupt, unpredictable and highly dangerous. Firefighters are warned about entering rooms or buildings not knowing the state of things. For a growing or fuel-controlled fire one might be able to crawl into the room for rescue purposes. If the room has "flashed over", the flames coming out the door will prevent entry. It is likely that the fire will extend to the corridor and adjacent parts of the building are now in grave danger. Inspection of the enclosure after a fire often will reveal the telltale signs of flashover--every combustible in the room will exhibit some degree of fire damage, if not totally destroyed, even to charring of the paint and paper on gypsum walls.

5.5.6 References

(1) Fire Protection Handbook, 14th edition. Boston, National Fire Protection Assoc., 1976, p. 6-47.

(2) McElroy, J. K. The Hotel Winecoff Disaster. NFPA Quarterly, Vol. 40, No. 3, pp. 140-159, January 1947.

(3) Clevely, H. Famous Fires. New York, John Day Co., 1958. p. 37.

6. Sources of Information

6.1 FEDERAL ORGANIZATIONS

The following organizations are engaged in activities which will lead to more effective fire investigations. Although this list may not be complete, it will provide access to one or more agencies which may provide assistance. To obtain the most direct telephone number, contact the Federal Information Center, 202/755-8660.

Bureau of Alcohol, Tobacco, and Firearms
1200 Pennsylvania Avenue, N.W.
Washington, DC 20226
Explosives Enforcement Branch
Explosives Technology Branch
Forensic Branch

Federal Bureau of Investigation
9th & Pennsylvania Avenues, N.W.
Washington, DC 20535

Law Enforcement Assistance Administration
633 Indiana Avenue, N.W.
Washington, DC 20531
National Institute of Law Enforcement & Criminal Justice

National Bureau of Standards
Washington, DC 20234
Center for Fire Research
Law Enforcement Standards Laborarory

National Fire Academy
U.S. Fire Administration
Route 1, Box 10A
Emmittsburg, MD 21727

National Transportation Safety Board
800 Independence Avenue, N.W.
Washington, DC 20594

U.S. Fire Administration
2400 M Street, N.W.
Washington, DC 20472
Office of Planning and Education

U.S. Forest Service
P.O. Box 2417
Washington, DC 20013

U.S. Postal Service
Chief Postal Inspector
475 L'Enfant Plaza West SW.
Washington, DC 20260

6.2 PRIVATE ORGANIZATIONS

The following organizations can provide fire investigators with additional information on fire investigations. Each organization must be contacted to determine the scope and the cost, if any, of their information packages.

Robert J. Brady Company
The Charles Press Publishers, Inc.
Bowie, MD 20715

Factory Mutual Research Corporation
1151 Boston-Providence Turnpike
Norwood, MA 02062

Film Communicators
11136 Weddington Street
No. Hollywood, CA 91601

Glencoe Press
Riverside, NJ 08075

Industrial Risk Insurers
85 Woodlawn Street
Hartford, CT 06102

Insurance Crime Prevention Institute
15 Franklin Street
Westport, CT 06880

International Association of Arson Investigators, Inc.
97 Paquin Drive
Marlboro, MA 01752

International Association of Fire Photographers
Box 201
Elmhurst, IL 60126

National Automobile Theft Bureau
390 North Broad, Room 350
Jericho, NY 11753

National Fire Protection Association
470 Atlantic Avenue
Boston, MA 02210

Underwriters Laboratories, Inc.
333 Pfingsten Road
Northbrook, IL 60062

Appendix A. Municipal Task Forces

INTRODUCTION

- Solution of the arson problem requires effective planning and a high level of commitment from public and private organizations on the local level

- Success depends on coordination of efforts for both prevention and control of arson

    -- Responsibility for arson prevention and control usually involves cooperation among several agencies

    -- Minimally, the following are involved:

        - Mayor/city manager
        - Fire Department
        - Police Department
        - Prosecutor's office

- Initial role of task force is to identify problem, focus interest, and provide a forum for developing community policy.

- Roles naturally evolve to include implementation responsibilities for specific programs

BUILDING A MUNICIPAL ARSON TASK FORCE

1. DETERMINE TASK FORCE STRUCTURE AND AREAS OF RESPONSIBILITY

The first step is to decide those agencies and groups in your community which have key responsibilities and interests in solving the arson problem. Each community is organized differently so you will have to determine the appropriate parties for your community. To provide some guidance, the organization of a typical Arson Task Force is presented below:

MEMBER	RESPONSIBILITIES
Mayor's Office	Provides executive direction, executive guidance, and policy
Fire Department	Arson investigation, prevention activity, recordkeeping, information analysis and trends, public education and awareness
Police Department	Investigate assistance, prevention assistance, lab analysis, records and information, training assistance, and patrol assistance
Prosecutor's Office	Criminal prosecution advice, fraud investigation, and prosecution
City Council Public Safety Committee	Policy direction and impetus ordinance review, policy development, and on-going policy change as related to arson, public education and awareness
Insurance Industry	Material and technical assistance, insurance arson prevention, incentive award programs for apprehension and prosecution, and industry-wide insurance information
Sheriff's Office	Investigative assistance, communication and information exchange in unincorporated areas adjacent to the city.
Chamber of Commerce	Business and community participation, business trends, community awareness

The task force concept is flexible and should be adjusted to fit the specifics of your community. Arson task forces have been successful in a variety of different cities, including San Francisco, Seattle, Dallas, and Winston-Salem.

The essential job of the arson task force is to provide the conceptual framework and coordination necessary to establish a system for the prevention and control of arson. Usually the mayor/city manager acts as task force chairperson and is responsible for providing overall executive direction and guidance.

The important thing is to ensure that all of the key roles have been identified so that progress can occur from the initial task force meeting. The responsibilities and jurisdictional roles will be developed from that point on.

2. OBTAIN COMMITMENT FROM TOP PEOPLE

It is vitally important to have the approval, if not the actual involvement, of the top person in each organizational element involved in the task force.

A) Involve the press

Once a problem has been publicly discussed it is much easier to get high level attention. It is never too early to involve the media. You may begin by preparing a press report on some recent arson locally and then do an article on the arson problem in general (see the overview of the U.S. Fire Administration's Report to Congress on Arson).

B) Start with the private sector

Since the insurance industry usually is active in arson prevention, it may be useful to start there before approaching the mayor and the other government agencies. In Seattle, the Washington Insurance Council was very active in the fight against arson and provided task force assistance.

C) Develop an effective presentation

In your presentation to these individuals be prepared to describe the seriousness of the arson problem and its multiple affects on the community and the need for an organized effort to control arson.

3. GET EACH AGENCY TO ASSIGN A SPECIFIC PERSON

After obtaining general commitment to the task force concept from the top individual, be sure that a specific person, with appropriate authority and expertise, is assigned by each agency to participate in the task force. Responsibilities and task force organization will be decided during meetings, therefore it is essential to have the participation and involvement of a person with decision-making authority who can make resource commitments.

4. SCHEDULE AN INITIAL SERIES OF MEETINGS TO ORGANIZE THE TASK FORCE

When all the agencies have assigned representatives, a series of meetings should be scheduled to begin the process of organizing the task force.

The task force functions in two ways: it provides a forum for setting community policy on arson and it acts as an operational force to implement specific programs and ideas. One approach to task force organization that has proved effective is to form subcommittees, or working groups, for each major problem area. For each group the general assignment would be:

A) Identify and define the problem

B) Determine what is presently being done

C) Develop specific recommendations, with a priority ranking, for improvement

D) Establish appropriate measures of success and recommend short-range objectives and long-term goals.

The task force as a whole would then review the recommendations from each working group and establish actual priorities, objectives, and goals for the task force in a consistent fashion. Responsibility for implementing selected ideas would then be assigned as the task force felt appropriate.

Depending on your community, the operational force head may be within the fire department, prosecutor's office, police department, or sheriff's office.

The task force operates as a coalition. The process of organizing is obviously political and will depend on the forces within your community. It requires the active support of the executive and legislative branches in order to be successful in preventing and controlling arson.

The entire task force then would review the recommendations from each working group and establish priorities, objectives, and goals for the task force in a consistent fashion. Responsibility for implementing selected programs would then be assigned. This approach ensures that all programs are contributing to the task force goals through a comprehensive strategy.

The two major functional areas are arson prevention and control. Figure A-1 shows one approach to organizing the major working areas in an arson program. Not all the functions listed in figure A-1 may be appropriate to your community, but most of them do occur in successful programs.

5. SPECIFIC ACTION ITEMS FOR THE TASK FORCE

In addition to organizing, there are some specific action items for the task force to begin work on during initial meetings.

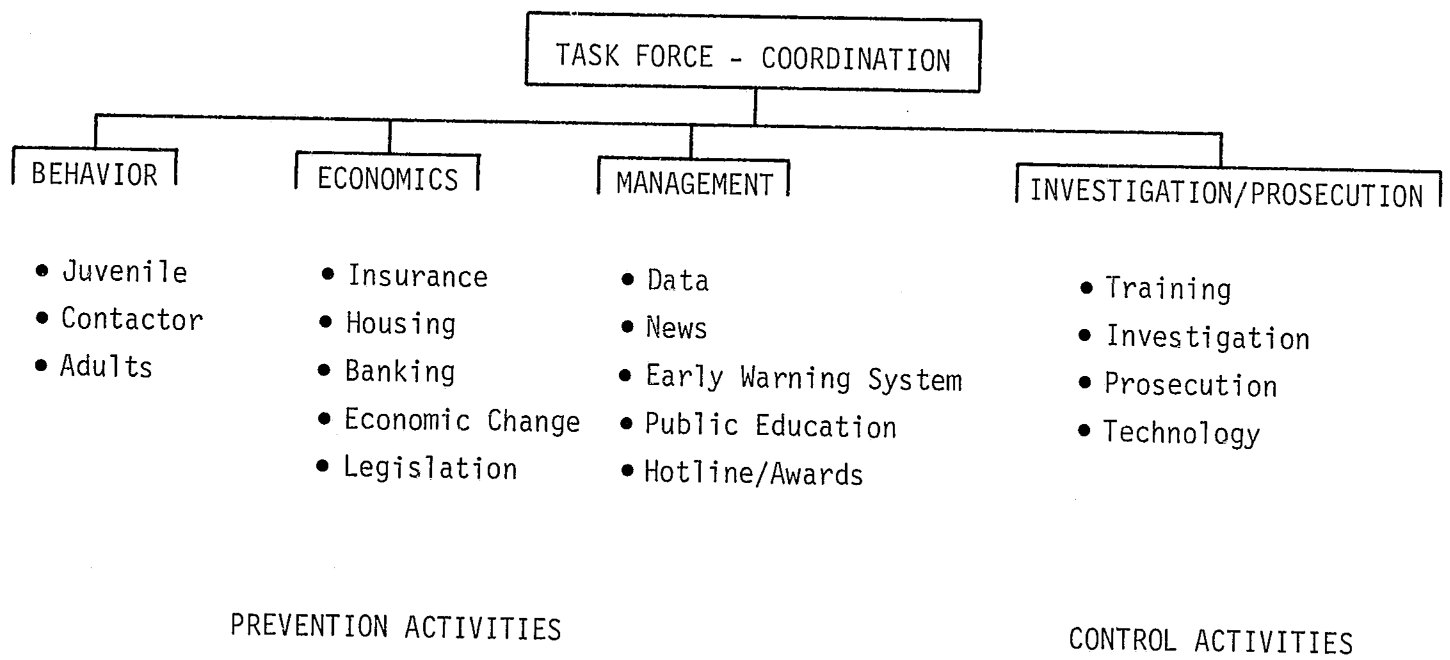

Figure A-1 Arson Task Force Working Areas

A) Define the local arson problem in detail

Using the immediately available statistics, a report should be prepared on the arson problem in your community. It is important to have quantitative information about arson in order to evaluate the prevention and control efforts. It should show the magnitude of the local arson problem in terms of: number and types of fires, frequency of incidents, deaths and injuries, property losses, and arrests and convictions.

In New Haven, for example, the arson problem had escalated from 1973 to 1976 to the point where nearly a third of all building fires had suspicious origins. Only after a grand jury report on arson was released and the data reviewed did the magnitude of the problem become apparent.

B) Develop a comprehensive arson strategy

By developing long-term goals and short-range objectives for arson prevention and control activities, a framework is established for making sound decisions about future steps.

As an example, the initial recommendations in the first report of Seattle's Arson Task Force included the following:

- Expand the fire department's Arson Investigation Unit
- Detail detectives from the police department to the Arson Investigation Unit. Individual tours would be from 6 to 12 months.
- Operationally the police detectives would serve under the Fire Chief while remaining under the administrative control of the Police Chief.
- The police detectives would maintain regular contacts with the police department's Criminal Investigation Unit.
- Arson investigative skills would be improved by a new arson training program.

C) Begin the process of public education on arson

It is essential to have community-wide involvement and awareness in order to control arson. The importance of publicity and public education in preventing arson cannot be over-emphasized. Begin by announcing the formation of the task force in the local media. Then concentrate on publicizing the organizational activities of the task force.

Seattle's program featured a quote by Fire Chief Frank Hanson: "If you start a fire in Seattle, you stand a good chance of getting caught. If you are caught, you stand an even better chance of going to jail." Subsequent arrests and convictions were publicized with a referral to the quote to emphasize Seattle's commitment to stopping arson.

D) Mobilize all available resources

Since arson is a local problem, existing budgets and local resources should be allocated to start the task force and to provide continuing support. Efforts should be initiated, however, to solicit financial and/or technical assistance through state and federal agencies, such as HUD (Dept. of Housing and Urban Development), LEAA (Law Enforcement Assistance Administration), or USFA (U.S. Fire Administration). Assign responsibilities for identifying appropriate programs and determining their application procedures.

You may find that the increased cooperation between agencies resulting from the task force defining responsibilities will increase available resources. This occurs when the cooperating agencies become more aware of each others' services and how to request and utilize them.

E) Begin the process of task force education

Task force members should become familiar with the details of other successful arson control efforts across the country.

6. SOME FINAL THOUGHTS

By now, your task force should be functioning and responding to local circumstances. The most important, long-term, operational goal is to maintain a spirit of cooperation and involvement. One way to help maintain commitment is to make sure that the "glory" is shared; for example, press releases should come from the Arson Task Force as a whole.

As arson prevention and control receives more attention, there will be an increasing potential for problems between agencies. This is why a clear delineation of agency responsibilities and a prioritization of tasks must occur at the task force level. The Arson Task Force can prevent the occurrence of counterproductive competition among agencies for the finite resources which are available to combat arson.

As your program begins to have impact, evaluation of the data should show a decline in your arson problems and this positive feedback will be helpful. In reviewing data, remember that the task force should set short-range objectives that can be achieved as well as long term goals that are well beyond your immediate grasp. These goals and objectives can then be periodically reviewed and adjusted to current circumstances.

ADDITIONAL INFORMATION

See the U.S. Fire Administration's "Arson Resource Directory", "Report to the Congress - ARSON the Federal Roles in Arson Prevention and Control", and their magazine "Arson Resource Bulletin". For information on these publications write directly to the U.S. Fire Administration.

The U.S. Fire Administration also has a program of technical assistance for Arson Task Forces.

Appendix B. The Investigator, as an Expert Witness for the Prosecution

INTRODUCTION

In the prosecution of criminal cases the jury and/or the court trying a case is often confronted with facts and circumstances that are beyond their areas of experience and expertise. It is in these special circumstances that the Expert Witness is brought into the case to provide the special or technical knowledge that is necessary to completely understand the case. The expert witness' testimony is admissible, not only to the facts, but also the opinions respecting the facts. The purpose of the testimony and opinion is to assist the jury in reaching a verdict.

EXPERT TESTIMONY

The expert witness, the chemist, the engineer, the technician, etc., is thus one who is fitted by education and/or experience, in a particular trade, calling, or profession, to be of assistance to the court in explaining the relationship to one another of the facts submitted in the case, or the results to be expected from such facts. The distinguishing characteristics of an expert is that the expert may properly be asked to state an opinion on subjects within the scope of his/her expert knowledge. Thus, the expert's opinion as evidence is admissible respecting a state of fact within a speciality.

ROLE OF THE EXPERT WITNESS

The prosecution of arson cases will most often require the assistance of experts both in the analysis, preparation, and evaluation of evidence and in relating findings or opinions in court testimony. It must be remembered that the findings of an expert, when testifying in an area of expertise, does have a direct bearing on the strength of the case.

Therefore, to utilize the unique abilities of the expert witness, prosecutors should be familiar with certain facts which may provide for the best utilization of this expert assistance. In several instances, cases have been weakened or even lost because of a misunderstanding in the line of questioning between the prosecutor and the witness. A new

CONTINUED

2 OF 3

question, harmless in the mind of the prosecutor when asked may "box in" the witness and give the defense new facts or strength for cross examination.

Generally, the expert is needed when a case contains items, materials, evidence, procedures, techniques, or analysis of a technical nature which requires classification or interpretation for court presentation. When such assistance is required prosecutors should request and utilize the services of an expert.

In general, the function of the fire investigator will be to support prosecution by:

(1) Determining point of origin, cause and responsibility, and providing physical evidence and/or testimony to support these contentions;

(2) produce audiovisual aids and/or exemplar materials to support the contentions;

(3) provide the prosecutor with an understanding of the principles, facts, and technical terminology which apply to the evidence and testimony to be presented;

(4) prepare testimony for use by the prosecutor covering the technical testimony to be presented.

The assistance to the prosecutor will generally be provided in two phases: (1) the pretrial conference; and (2) court presentation and testimony.

The pretrial conference provides the opportunity to assure that both the expert and the prosecutor are knowledgeable regarding the technical aspects of the case and the parameters of the expert testimony. Too often these elements are overlooked or compromised by the prosecutor, this is the exception not the rule.

ROLE OF THE PROSECUTOR

The complexity of an arson investigation and its prosecution are such that, for it to be successful, requires a responsibility on the part of the prosecutor. The following suggestions for prosecutor, although general, will help to insure the best utilization of expert witnesses:

(1) Listen to the methodology and suggestions of the expert;

(2) review the background material provided by the expert which is considered relevant to the case preparation;

(3) meet with the expert witness and make sure that the order, scope and objectives of the expert's testimony are fully understood;

(4) review the exhibits, audiovisual aids, or other materials the expert will use to support the findings and conclusions;

(5) when in court, ask only the questions which have been reviewed. New questions can be a disaster.

CONCLUSIONS

The information and suggestions presented herein are based in part upon many years of experience in successfully providing technical assistance and expertise in the investigation and prosecution of criminal cases. It is hoped that these guidelines will help to promote the establishment of a uniform and professional methodology for the use by technical experts.

BIBLIOGRAPHY

(1) Medico - Legal Bulletin, vol. 15, No. 9, 1966.

TEN COMMANDMENTS FOR AN EXPERT WITNESS*

(1) Prepare all basic exhibits and outlines of your testimony carefully; and arrange the same in orderly sequence, before you take the witness stand.

(2) Speak loud enough for the Court and counsel to hear; and don't talk too fast. Endeavor to obtain and hold the interest of the Court.

(3) Avoid unnecessary colloquy with either the Court or opposing counsel. Be courteous, fair, and frank. Keep calm; and be sure to hold your temper, even in trying circumstances.

(4) State your qualifications fully, but without "puffing" or indulgence in the trivial. And, don't be flattered or deterred by offers of opposing counsel to concede your qualifications; for this may be a trick to prevent the Court from learning how really important you are.

(5) After reviewing your qualifications, be prepared to state your opinion, as to the value or other factor regarding which you are to testify; and then be sure to follow this with a clear and adequate explanation of the methods which you employed in reaching your conclusion.

(6) Present your testimony as you would wish to have it presented if you were the Judge. Observe any doubts which may appear to arise in the Court's mind; and try to assist him in resolving them. After all, this is your primary function.

(7) Hold to the essentials of your testimony. Develop a sense of proportion; and don't get lost in unimportant detail.

(8) Face up to the strong points which may be presented by opposing witnesses; and endeavor to demonstrate that, while these should be given consideration, their weight is less than that of the points in your favor. Avoid the appearance of being an incorrigible partisan.

(9) If you are not prepared to answer a particular question, be honest enough to say so. A bluffer is easily detected; and then a cloud is cast over his entire testimony.

(10) Finally, be concise; and after you have made your point, stop talking.

*Based on Judge Pierce's presentation at the Engineers Institute, 1961.

Appendix C. Independent Testing Laboratories

	DOC FF1-70 Carpet Testing	ASTM E-84 Steiner Tunnel	NFPA-253 Flooring Radiant Panel	NFPA-258 Smoke Density Chamber	ASTM E-162 Radiant Panel
Better Fabrics Testing Bureau 101 West 31st Street New York, NY 10001 212/868-7090	X			X	
Certified Testing Labs., Inc. P.O. Box 2041 Dalton, Georgia 404/226-1400	X		X	X	X
Commercial Testing Company 407 Central Avenue Dalton, Georgia 30720 404/278-3935	X	X	X	X	
Hardwood Plywood Mfgs. Assoc. 2310 S. Walter Reed Road Arlington, Virginia 22206 703/435-2900		X		X	X
Independent Textile Testing Service 1499 Murray Avenue P.O. Box 1948 Dalton, Georgia 30720 404/278-3013					
LeBlanc Research Corp. 5454 Post Road East Greenwich, R.I. 02818 401/884-5785	X				
Southwest Research Institute 8500 Culebra Road San Antonio, Texas 78284 512/684-5111	X	X	X	X	X
Underwriters Laboratories 333 Pfingsten Road Northbrook, Illinois 60062 312/272-8800	X	X	X	X	X
United States Testing Company 1415 Park Avenue Hoboken, New Jersey 07030 201/792-2400	X	X	X	X	X

*This list is intended only as a guideline. For additional testing laboratories, the local classified section (the yellow pages) of the telephone book should be consulted.

Appendix D. Books of Interest

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Appendix E. List of Contributors

Francis L. Brannigan
University of Maryland
Fire & Rescue Institute Adjunct Staff
College Park, MD 20740
(Editor)

Vincent M. Brannigan
Department of Textile and Consumer Economics
University of Maryland
College Park, MD 20742
(Ch. 2.2, Legal Problems)

Richard G. Bright
Center for Fire Research
National Bureau of Standards
Bldg. 224, Rm. A 263
Washington, DC 20234
(Editor; Ch. 4.6, Explosions)

James E. Brown
Center for Fire Research
National Bureau of Standards
Bldg. 224, Rm. A 363
Washington, DC 20234
(Ch. 1.2, Accelerants)

William H. Elsey
EMMA, Inc.
5230 Navaho Drive
Alexandria, VA 22312
(App. A, Arson Task Force)

Richard G. Gann
Center for Fire Research
National Bureau of Standards
Bldg. 224, Rm. B 260
Washington, DC 20234
(Ch. 4.1, Flaming Ignition;
Ch. 4.2, Smoldering Combustion)

Albert W. Gleason
Bureau of Alcohol, Tobacco and Firearms)
Department of the Treasury
Washington, DC 20226
(App. B, Expert Witness)

Mohamed M. Gohar
State of Ohio
Division of State Fire Marshal
State Arson Bureau
8895 E. Main Street
Reynoldsburg, OH 43068
(Ch. 1.5, Photography and related figures)

Daniel Gross
Center for Fire Research
National Bureau of Standards
Bldg. 224, Rm. B 250
Washington, DC 20234
(Ch. 3.1, Building Construction;
Ch. 3.2, Materials)

Steve W. Hill
National Fire Academy
U.S. Fire Administration
Route 1, Box 10A
Emmitsburg, MD 21727
(Ch. 1.1, Cause and Origin)

Clayton Huggett
Center for Fire Research
National Bureau of Standards
Bldg. 224, Rm. A 249
Washington, DC 20234
(Ch. 5.1-5.4, Chemistry and Physics)

David J. Icove
Incendiary Crime Analysis Unit
Knoxville Fire Department
800 East Church Avenue
Knoxville, TN 37915
(Ch. 1.5, Photography and related figures)

Nora H. Jason
Center for Fire Research
National Bureau of Standards
Bldg. 224, Rm. B 250
Washington, DC 20234
(Editor; Ch. 6, Sources of Information)

Frank B. Kaye
Chief Fire Marshal
Arlington County Fire Department
1020 North Hudson Street
Arlington, VA 22201
(Ch. 1.6, Recordkeeping)

John P. Keating
Psychology Department, NI-25
University of Washington
Seattle, WA 98195
(Ch. 2.1, Interviewing)

Robert J. Kelly
Consumer Product Safety Commission
5401 Westbard Avenue
Bethesda, MD 20207
(Ch. 4.5, Electrical Fires and related figures)

Joseph J. Loftus
Center for Fire Research
National Bureau of Standards
Bldg. 224, Rm. A 345
Washington, DC 20234
(Ch. 4.2, Smoldering Combustion)

John W. Lynch
Office of Planning and Education
U.S. Fire Administration
2400 M Street, NW.
Washington, DC 20230
(App. A, Arson Task Force)

Bernard J. McCaffrey
Center for Fire Research
National Bureau of Standards
Bldg. 224, Rm. B 356
Washington, DC 20234
(Ch. 5.5, Fire Development)

William J. Meese
Center for Building Technology
National Bureau of Standards
Bldg. 226, Rm. B 306
Washington, DC 20234
(Ch. 4.4, Electrical Fires and related figures)

Victor U. Palumbo
National Fire Academy
U.S. Fire Administration
Route 1, Box 10A
Emmitsburg, MD 21727
(Ch. 1.1, Cause and Origin)

Alexander F. Robertson
Center for Fire Research
National Bureau of Standards
Bldg. 224, Rm. A 249
Washington, DC 20234
(Ch. 4.3, Spontaneous Ignitions)

James C. Robertson
Maryland State Fire Marshal
301 W. Preston Street
Baltimore, MD 21201
(Ch. 1.3, Tools & Equipment;
Ch. 1.7, Firefighter)

Willis T. Swartz
Deputy Fire Marshal
Arlington County Fire Department
1020 North Hudson Street
Arlington, VA 22201
(Ch. 1.6, Recordkeeping)

Bertram M. Vogel
Center for Fire Research
National Bureau of Standards
Bldg. 224, Rm. B 250
Washington, DC 20234
(Ch. 3.3, Utility Systems)

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The Handbook is a reference tool designed to be used by the beginning or by the experienced fire investigator. How each person uses this book will depend upon a particular need and level of experience. The broad areas covered are: Fire Ground Procedures; Post-Fire Interviews; The Building and Its Makeup; Ignition Sources; the Chemistry and Physics of Fire and Sources of Information. The appendices have sections on how to organize an arson task force; the expert witness; independent testing laboratories; and selective bibliography.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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